unit

20 D
Human Systems

The human body is organized into a number of different organ systems. Each of these organ systems has a critical role in maintaining your health. For example, your cardiovascular system transports nutrients and oxygen to your cells, and wastes and carbon dioxide from your cells. Elite athletes, such as the Olympic gold-medal winner Chandra Crawford, must have a healthy cardiovascular system. Unfortunately, cardiovascular disease is the leading cause of death in North America. About 44 000 Canadians, 40 % of them younger than 65, die each year from cardiovascular disease. Over 4000 patients in Canada and the United States are on the waiting list for a new heart.

Dr. Michael Sefton, director of the Institute of Biomaterials and Biomedical Engineering at the University of Toronto, is developing a possible way to provide an almost unlimited number of hearts for transplant. Sefton's "heart in a box" is a transplantable heart that can be grown in the laboratory. First, researchers create scaffolding—a supporting framework—of biodegradable plastic around which the cells will grow. Next, they seed the scaffolding with living cells and place it in an incubator that maintains constant temperature and provides nutrients and oxygen. Although researchers have not yet been able to grow a complete living heart, they have successfully grown components of the heart.

As you progress through the unit, think about these focusing questions:

- How do specialized structures function in the overall biochemical balance of the living system?
- What conditions result if these structures do not function normally?

UNIT 20 D PERFORMANCE TASK

Determining Fitness Level

Despite the increase in performance of elite athletes, the fitness level of the general public has been decreasing. The ability to perform physical activity depends on your body's ability to deliver oxygen to your cells. How can you design a fitness test to determine the amount of oxygen being delivered to your tissues? At the end of this unit, you may apply your skills and knowledge to complete this Performance Task.

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GENERAL OUTCOMES

In this unit, you will

- explain how the human digestive and respiratory systems exchange energy and matter with the environment
- explain the role of the circulatory and defence systems in maintaining an internal equilibrium
- explain the role of the excretory system in maintaining an internal equilibrium in humans through the exchange of energy and matter with the environment
- explain the role of the motor system in the function of other body systems

Unit 20 D

Human Systems

ARE YOU READY?

Prerequisites

Concepts

- cells, organs, tissues, systems
- structure and function
- response to stimuli
- active and passive transport

Skills

- state a prediction and a hypothesis
- identify major variables
- organize data in appropriate formats
- interpret patterns and trends in data
- state a conclusion based on experimental data

You can review prerequisite concepts and skills on the Nelson Web site and in the Appendices.

A Unit Pre-Test is also available online.

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These questions will help you find out what you already know, and what you need to review, before you continue with this unit.

Knowledge

1. Examine **Figure 1** and explain the function of each of the labelled tissues.

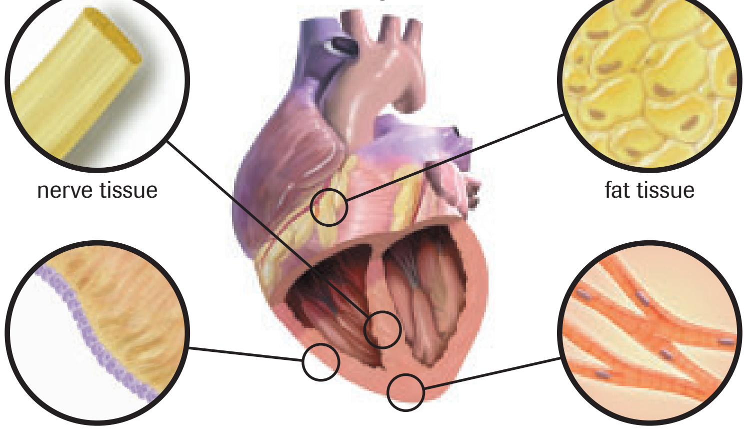


Figure 1
Tissues of the human heart

2. Explain what happens to an animal cell placed in
   (a) a hypertonic solution;
   (b) a hypotonic solution.

3. Copy **Table 1** into your notebook and fill in the blank spaces.

Table 1 Cellular Organization of Some Organ Systems

Level of cellular organization		Excretory system	
organ	ovary		
tissue		epithelial, blood, nerve, fat (adipose), and connective	
cell	egg		white blood cell (leukocyte)

4. In **Table 2**, match the organ(s) with the corresponding regulatory function. (*Note:* An organ can have more than one function, and a function can be linked to more than one organ.)

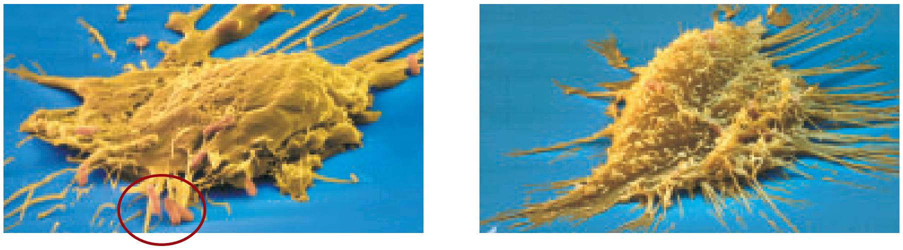
Table 2 Regulatory Functions of Some Organs

Organ(s)	Regulatory function
(a) skin	(i) disease prevention
(b) lymph vessels and lymph nodes	(ii) thermoregulation (regulation of body temperature)
(c) pancreas	(iii) maintaining blood sugar
(d) heart	(iv) maintaining blood pressure
(e) kidneys	(v) maintaining blood pH

Skills and STS Connections

5. A group of students conducts an experiment to determine how the body responds to stress. An ice cube is placed on the back of a subject's neck while another group member monitors changes in the subject's pulse.
   (a) Why is pulse used to monitor stress?
   (b) Create a hypothesis for the experiment.
   (c) Identify the manipulated and responding variables in the experiment.
   (d) What variables must be controlled to obtain reliable data?
   (e) Design a data table for the experiment.
   (f) Would you expect identical data from different subjects? Explain your answer.
   (g) Through the course of the experiment, when would you take the pulse? Give your reasons.
   (h) What practical information might the experiment provide?

6. **Figure 2** shows a white blood cell at two consecutive times.



(a) **(b)**

Figure 2
(a) At the first time point, bacteria cells (shown in the circle) are on the surface of the white blood cell.
(b) At the second time point, the bacteria cells are no longer visible.

   (a) Describe what is happening in **Figure 2**. Draw a conclusion from the photos.
   (b) Explain how this process helps to maintain a balanced internal environment.

7. Scientists monitored six types of ions in the cells of *Sargassum* (a brown alga often called seaweed) when maintained in brackish water (a mixture of salt and fresh water) and in marine water (seawater). The scientists noted that the concentration of ions did not change. The results are shown in **Table 3**.

Table 3 Ion Concentrations of *Sargassum* Cells

	Ion concentration*		
Ion	**Cell**	**Marine water**	**Brackish water**
calcium	1.7	12	1.7
magnesium	0.005	57	6.5
sulfate	0.01	36	2.8
sodium	90	500	60
potassium	490	12	1.4
chloride	520	520	74

*All concentrations are measured in mmol/L.

Assume that the cell membrane is permeable to all of the ions.
   (a) Which ion must be actively transported inside the cell in both brackish water and marine water? Explain your answer.
   (b) Which ion enters the cell by diffusion from marine water, but must be actively transported inside the cell from brackish water? Explain.
   (c) Explain how a cell could maintain its sodium ion concentration despite living in marine or brackish water environments.

chapter 8

Nutrients, Enzymes, and the Digestive System

In this chapter

- Exploration: Canada's Food Guide to Healthy Eating
- Chemistry Connection: Polymers
- Investigation 8.1: Identifying Carbohydrates
- Case Study: Fats and Health
- Investigation 8.2: Identifying Lipids and Proteins
- Explore an Issue: Irradiation Technology
- Investigation 8.3: Factors That Affect the Catalase Enzyme Reaction
- Explore an Issue: Fad Diets
- Web Activity: What Are You Eating?
- Investigation 8.4: Effect of pH and Temperature on Starch Digestion
- Mini Investigation: Emulsification of Fats

Canada has a multicultural society, which includes a wide variety of foods and styles of cooking. The foods of various cultures differ not only in flavour, but also in the types of ingredients used (**Figure 1**, next page).

Different diets may result in unique health problems. The high rate of heart disease in North America is due in part to the large amounts of fat consumed. Some people have decided that a vegetarian diet is healthier. Recently, high-protein, low-carbohydrate diets have become popular. However, diets high in animal protein also have higher amounts of cholesterol and saturated fats, which have been linked with cardiovascular disease.

The digestive system is responsible for converting the components of our diets into the molecules that are taken up and used by the cells of the body. Once inside the cells, these molecules supply the body with energy and the raw materials for the synthesis of essential chemical compounds used for growth, maintenance, and tissue repair.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Make a list of the essential nutrients that must be included in every diet.
2. Copy and complete the chart below in your notebook.

Nutrient	Undergoes digestion? yes	Undergoes digestion? no	Components after digested	Use by the body
protein				build structure
vitamins				coenzymes: assist enzymes, bind to substrate molecules
fats			fatty acid + glycerol	
polysaccharides				
water				

3. Make a list of the digestive system organs that you already know.

Career Connections:
Registered Dietician; X-ray Technician; Health Service Administrator

Figure 1
Typical cuisine from **(a)** North America, **(b)** Japan, **(c)** China, **(d)** South America

Exploration — *Canada's Food Guide to Healthy Eating*

- Go to the Nelson Web site and find the link to Health Canada's Food Guide to Healthy Eating.

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(a) What recommendations does the food guide give? Why do you think it is recommended to eat large amounts of some foods and smaller amounts of others?

(b) According to the guide, which foods should be eaten in larger quantities? Which foods should be eaten in smaller quantities?

(c) Write down everything you might eat on a typical day. Score yourself using the Healthy Eating Scorecard.

(d) Research the typical daily diet of a person from a different culture in a country outside of North America. Compare your diet to it.

8.1 Essential Nutrients

Living things are composed of nonliving chemicals (**Figure 1**). Proteins, carbohydrates, lipids (fats), vitamins and minerals, and nucleic acids are often categorized as the chemicals of living things despite the fact that none of them are capable of life by themselves.

Scientific investigations have shown that the same principles of chemistry apply in both the physical world and the living world. An understanding of life comes from an understanding of how chemical reactions are regulated within cells.

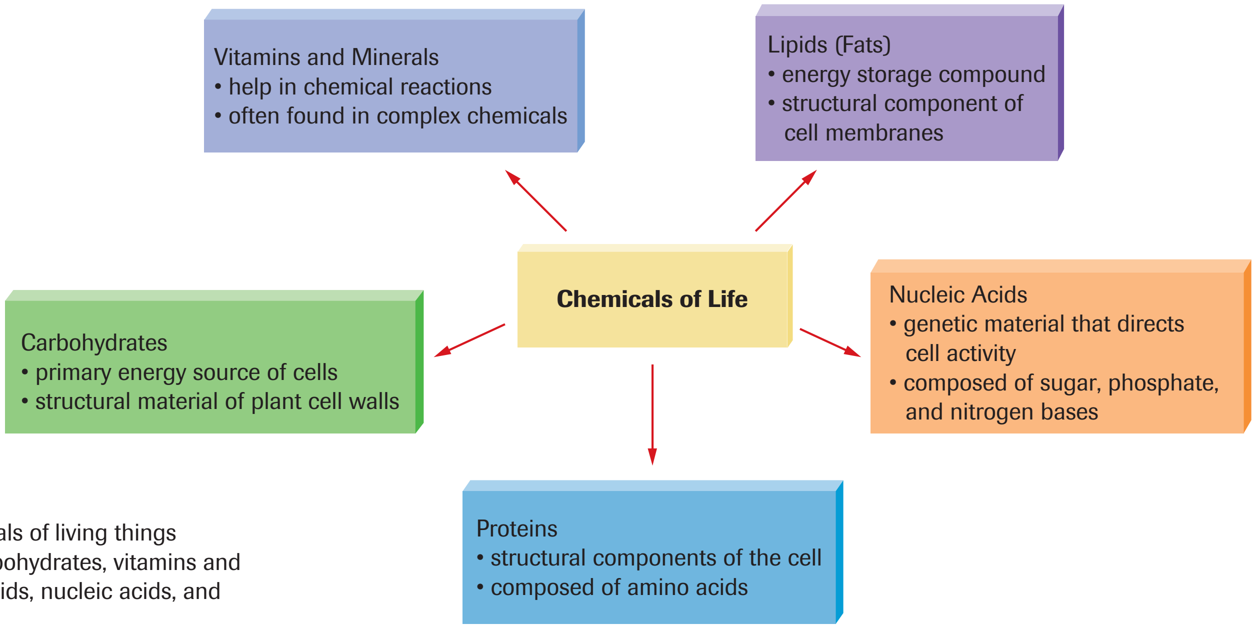

Figure 1
The chemicals of living things include carbohydrates, vitamins and minerals, lipids, nucleic acids, and proteins.

The foods you eat can be classified into three major groups of nutrients: carbohydrates, proteins, and lipids. These nutrients make up the bulk of what you eat. Vitamins and minerals are also required, but in much smaller amounts. Water is also essential for life, although it is not considered a nutrient. Most of the food you eat is a combination of nutrients. For example, the cereal you eat for breakfast or the bowl of vegetable soup you have for lunch is a combination of carbohydrates, proteins, and lipids, as well as some vitamins and minerals.

Carbohydrates

carbohydrate a molecule composed of sugar subunits that contain carbon, hydrogen, and oxygen in a 1:2:1 ratio

Carbohydrates are often described as energy nutrients. They provide a fast source of energy and make up the largest component in most diets. Potatoes, bread, corn, rice, and fruit contain large amounts of carbohydrates. Marathon runners often consume large quantities of carbohydrates a few days before a race to make sure that they have maximum energy reserves. However, under normal circumstances, it is not a good idea to eat excess quantities of carbohydrates because they will be stored as fat.

The human body is not able to make carbohydrates. You rely on plants as your source of carbohydrates. Using energy from the Sun, plants combine carbon dioxide and water to synthesize carbohydrates through the process of photosynthesis.

Carbohydrate Chemistry

Carbohydrates are either single sugar units or **polymers** of many sugar units. Single sugar units usually contain carbon, hydrogen, and oxygen in a 1:2:1 ratio. For example, triose sugars have the molecular formula $C_3H_6O_3$, and hexose sugars have the molecular formula $C_6H_{12}O_6$. The word *triose* refers to the fact that the sugars have a three-carbon chain (the prefix *tri-* means three). Hexose sugars contain six-carbon chain sugars (the prefix *hex-* means six). Many of the most important sugars contain either three-, five-, or six-chain sugars. Those that contain more than five carbons are often in a ring form.

Common sugars like glucose, found in human blood; fructose, a plant sugar commonly found in fruits; and deoxyribose, a sugar component of the DNA molecule, can be identified as sugars by the *-ose* suffix. Even the large molecule cellulose, which makes up plant cell walls, is a carbohydrate.

Carbohydrates can also be classified according to the number of sugar units they contain. **Monosaccharides** are the simplest sugars, containing a single sugar unit. Glucose, galactose, and fructose are three common monosaccharides. **Figure 2** shows that they are **isomers**—that is, all three molecules have the same molecular formula, $C_6H_{12}O_6$, but different structural arrangements. The different chemical properties of these monosaccharides can be explained by their different structural arrangements. For example, fructose is much sweeter than glucose and is often used by food manufacturers to sweeten their products. The three sugars rotate between the straight-chain form and the ring structure, shown in **Figure 2**.

polymer a molecule composed of three or more subunits

monosaccharide a single sugar unit

isomer one of a group of chemicals that have the same chemical formula but different arrangements of the atoms

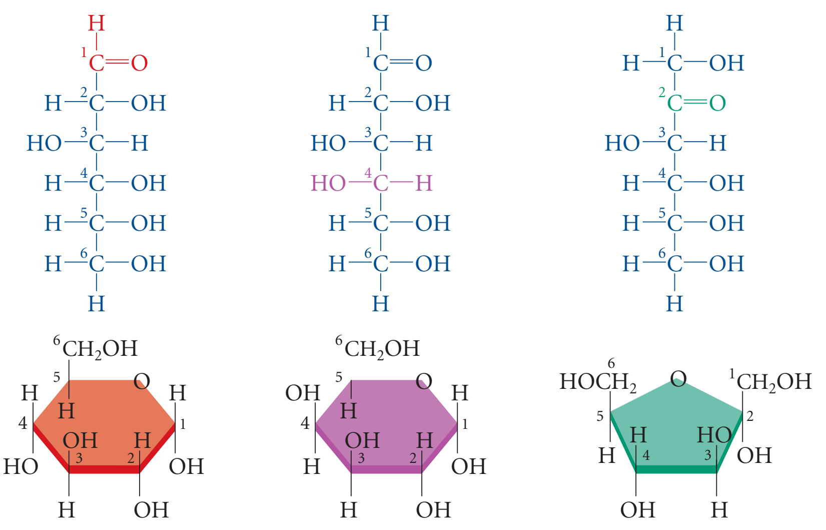

Figure 2
Glucose, galactose, and fructose are isomers.

The combination of two monosaccharides forms a **disaccharide**. Sucrose (white table sugar) is a disaccharide formed from glucose and fructose. Sucrose is extracted from plants such as sugar cane and sugar beet. Maltose (malt sugar) is a disaccharide formed from two glucose units. Maltose is commonly found in the seeds of germinating plants. Lactose (milk sugar) is composed of glucose and galactose units. All disaccharides are formed by a process called **dehydration synthesis** (or dehydrolysis), in which a water molecule is formed from the two monosaccharide molecules (**Figure 3**, next page). The opposite reaction is **hydrolysis**, in which a water molecule is used to break the bond of the disaccharide.

disaccharide a sugar formed by the joining of two monosaccharide subunits

dehydration synthesis the process by which larger molecules are formed by the removal of water from two smaller molecules

hydrolysis the process by which larger molecules are split into smaller molecules by the addition of water

EXTENSION

Condensation and Hydrolysis

View this animation of condensation (dehydration synthesis) and hydrolysis.

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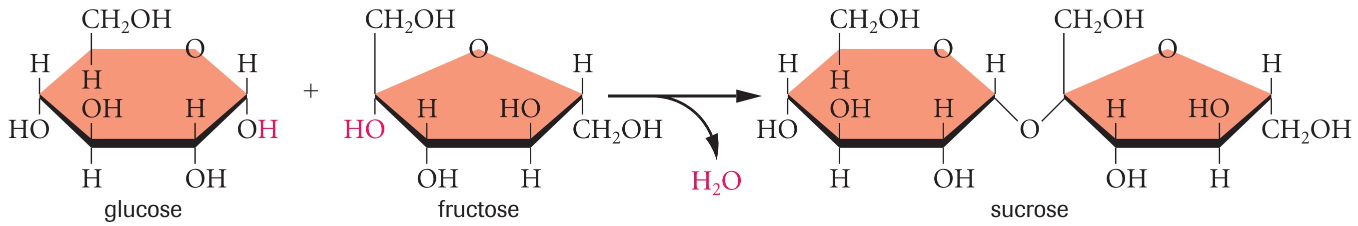

Figure 3
The formation of a disaccharide by dehydration synthesis. Note: Sucrose can only exist in the ring form.

polysaccharide a carbohydrate composed of many single sugar subunits

starch a plant carbohydrate used to store energy

Polysaccharides are carbohydrates formed by the union of many monosaccharide subunits. **Starch**, for example, is a plant polysaccharide that is composed of multiple subunits of glucose. Plants store energy in the chemical bonds of the starch molecule. Starches can exist in two different forms: amylose and amylopectin. Both molecules tend to bend in the shape of a helix, or coil (**Figure 4**). The amylose molecules contain up to 1000 or more glucose units with the first carbon of a glucose molecule linked to the fourth carbon in the next molecule (**Figure 4 (a)**). The amylopectins contain between 1000 and 6000 glucose subunits and have short branching chains of between 24 and 36 glucose units extending from the main branch (**Figure 4 (b)**).

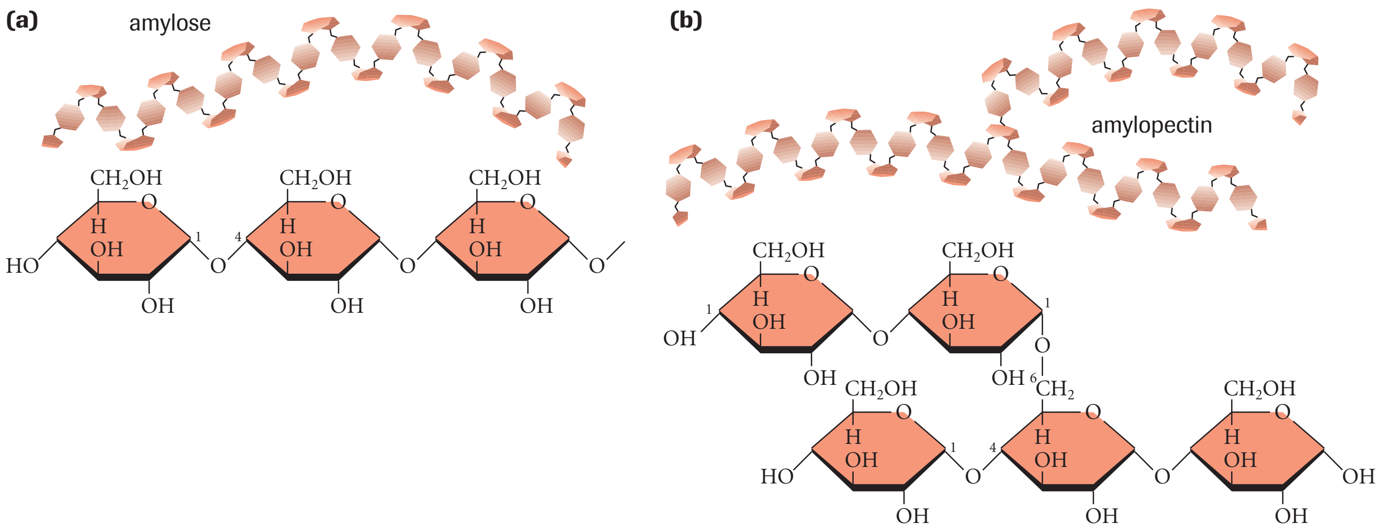

Figure 4
(a) Amylose is an unbranched polymer of glucose.
(b) Amylopectin is a branched polymer of glucose.

glycogen the form of carbohydrate storage in animals

cellulose a plant polysaccharide that makes up plant cell walls

Animals store carbohydrates in the form of a polysaccharide called **glycogen**. The structure of glycogen resembles that of the amylopectin starch molecule, except that its branching structures contain only 16 to 24 glucose units.

Plant cell walls are made up of the polysaccharide **cellulose**. Over 50 % of all organic carbon in the biosphere is tied up as cellulose. Cellulose molecules, like starch and glycogen, are composed of many glucose subunits. However, the bonding of the linking oxygen atoms differs between starch and cellulose; cellulose tends not to form coiled structures. The many layers of cellulose are attracted to one another by hydrogen bonds between the –OH groups (**Figure 5**, next page).

DID YOU KNOW?

Carbohydrates for Energy
Athletes often eat starches. Since these complex carbohydrates are broken down slowly, they provide a prolonged source of energy without dramatically changing blood sugar levels.

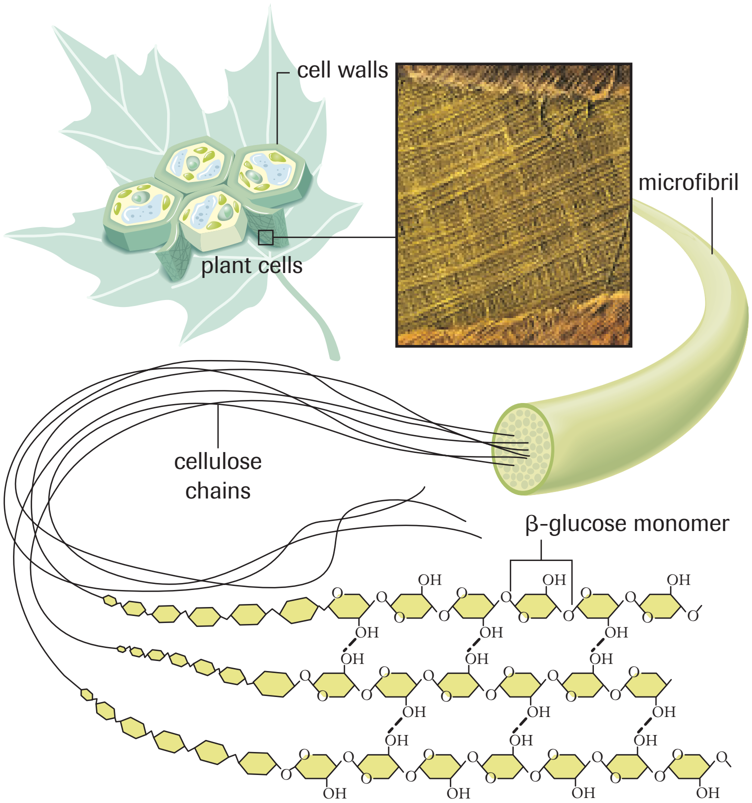

Figure 5
Cellulose fibres are composed of microfibrils, which are composed of many cellulose molecules held together by hydrogen bonds.

CHEMISTRY CONNECTION

Polymers
Glycogen, starch, and cellulose are three examples of naturally occurring polymers. Synthetic polymers, such as nylon, polyvinyl chloride, or polyesters, are commonly used in many consumer products. You can find out more information about polymers in your chemistry course.

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Practice

1. What is the primary function of carbohydrates?
2. Name three single sugars and indicate where you would expect to find these sugars.
3. Copy and complete the following table.

Table 1 Common Sugars

Sugar	Composed of	Source
maltose		
sucrose		
lactose		

4. What happens to carbohydrates that are not immediately used by your body? Why might you want to limit your carbohydrate intake?
5. How can you recognize ingredients on food labels that are sugars?
6. How are starch and cellulose alike? How do they differ?

EXTENSION

Hydrolysis and Dehydrolysis
Listen to this Audio Clip for an analysis of the important elements associated with the synthesis and digestion of organic molecules in living organisms.

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INVESTIGATION 8.1 *Introduction*

Identifying Carbohydrates

Different classes of carbohydrates react differently to the chemical reagent Benedict's solution. In this investigation, you will use Benedict's solution to determine which of three unknowns is a specific type of carbohydrate.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

To perform this investigation, turn to page 271.

Lipids

You may have noticed while doing dishes how fat floats on the surface of water. This is because lipids are nonpolar. They are insoluble in polar solvents such as water. Many lipids are composed of two structural units: glycerol and fatty acids. Like complex carbohydrates, glycerol and fatty acids can be combined by dehydration synthesis (**Figure 6**).

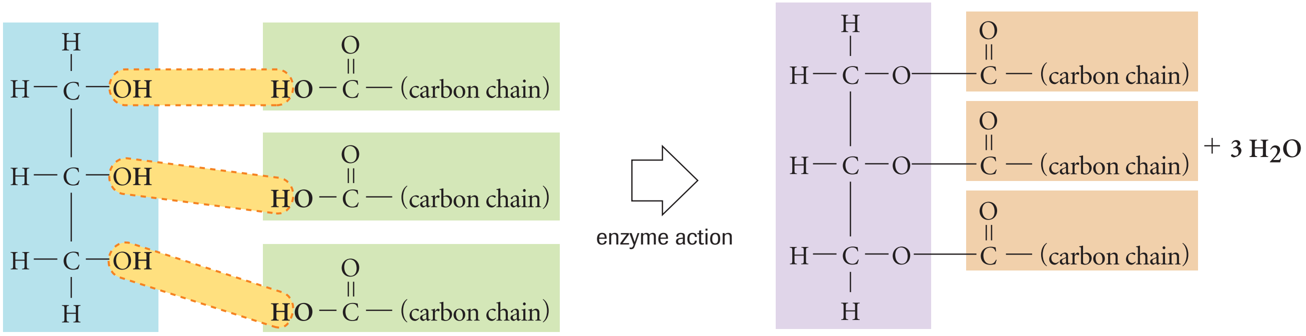

Figure 6

Triglycerides are formed by the union of glycerol and three fatty acids. Note the removal of water in the synthesis. The terms monoglyceride and diglyceride are used to describe the joining of glycerol with one or two fatty acids, respectively.

An important function of lipids is the storage of energy. Glycogen supplies are limited in most animals. Once glycogen stores have been built up, excess carbohydrates are converted into fat. This helps explain why eating carbohydrates can cause an increase in fat storage. Other lipids serve as key components in cell membranes, act as cushions for delicate organs of the body, serve as carriers for vitamins A, D, E, and K, and are the raw materials for the synthesis of hormones and other important chemicals. A layer of lipids at the base of the skin insulates you against the cold. The thicker the layer of fat, the better the insulation. Taking their cue from marine mammals, marathon swimmers often coat their bodies with a layer of fat before entering cold water.

triglyceride a lipid composed of glycerol and three fatty acids

fat a lipid composed of glycerol and saturated fatty acids; solid at room temperature

oil a lipid composed of glycerol and unsaturated fatty acids; liquid at room temperature

Triglycerides are formed by the union of glycerol and three fatty acids (**Figure 6**). Triglycerides that are solid at room temperature are called **fats**. Most of the fatty acids in animal fats are *saturated* (**Figure 7**). This means that only single bonds exist between the carbon atoms. Because the single covalent bonds tend to be stable, animal fats are difficult to break down. Triglycerides that are liquid at room temperature are called **oils**. The fatty acids of most plants are unsaturated. This means that they contain double bonds

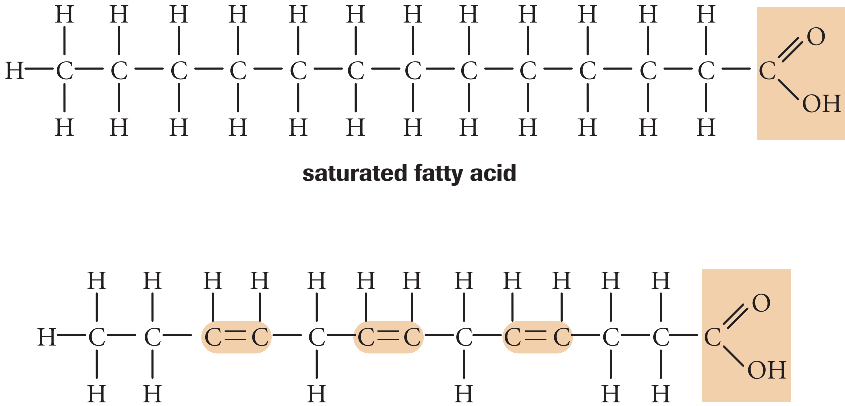

Figure 7

Saturated fats do not have double bonds between carbon atoms; unsaturated fats do.

between the carbon atoms. If the fatty acid contains only one double bond, it is monounsaturated; if it contains two or more double bonds, it is polyunsaturated. The unsaturated double bonds are somewhat reactive, and, therefore, plant oils are more easily broken down than animal fats.

A second group of lipids, called **phospholipids**, have a phosphate group bonded to the glycerol backbone of the molecule (**Figure 8**). The negatively charged phosphate replaces one of the fatty acids, providing a polar end to the lipid. The polar end of phospholipids is soluble in water, while the nonpolar end is insoluble. These special properties make phospholipids well suited for cell membranes.

phospholipid a lipid with a phosphate molecule attached to the glycerol backbone, making the molecule polar; the major components of cell membranes

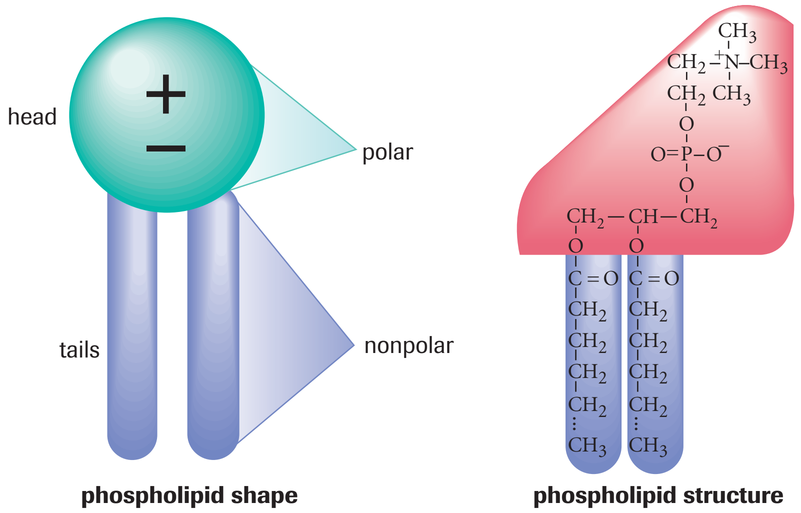

Figure 8
Phospholipid shape and structure. The phosphate group makes these lipids soluble in water as well as in lipids.

Waxes make up a third group of lipids. In waxes, long-chain fatty acids are joined to long-chain alcohols or to carbon rings. These long, stable molecules are insoluble in water, making them well suited as a waterproof coating for plant leaves or animal feathers and fur.

wax a long-chain lipid that is insoluble in water

Practice

7. What are fats?

8. What are the two structural components of fats?

9. How do saturated fats differ from unsaturated fats?

10. Are fats essential to your diet? Explain your answer.

Liposome Technology for Drug Delivery

Lipids can assemble themselves into double-layered spheres approximately the size of a cell. The spheres are known as liposomes. They function like cell membranes because they can fuse with a cell and deliver their contents to the cell's interior. Liposomes are used with cancer-fighting drugs to help the drugs target tumours. This helps to reduce unwanted side effects from drug interactions with healthy tissues and also enables patients to accept higher doses of anti-cancer drugs. One of these liposomal drugs was discovered by Dr. Theresa Allen and her research group at the University of Alberta.

Liposomes are also showing promise as a means of increasing the efficiency of gene therapy. Gene therapy is the process of introducing new genes into the DNA of a person's cells to correct a genetic disease. In a process similar to endocytosis, researchers have successfully inserted DNA into liposomes that have fused with target cells.

Case Study

Fats and Health

Although fats are a required part of your diet, problems arise when you consume too much. Doctors recommend that no more than 30 % of total energy intake be in the form of fats. Fats are concentrated energy sources containing more than twice as much energy as an equivalent mass of carbohydrate or protein. By eating 100 g of fat, you take in about 3780 kJ of energy. (The kilojoule, kJ, is a unit used to measure food energy.) By comparison, 100 g of carbohydrates or protein yield 1680 kJ of energy. When energy input or consumption exceeds energy output, the result is weight gain.

Heart disease has been associated with diets high in saturated fats. Recall that the single bonds between the carbon molecules make the fats stable. The stable fats tend to remain intact inside the cells of the body much longer than more reactive macromolecules. High-fat diets and obesity have also been linked to certain types of cancer, such as breast, colon, and prostate. Obesity has also been linked to high blood pressure and adult-onset diabetes. According to one report, over 80 % of people with adult-onset diabetes are overweight.

The Cholesterol Controversy

Heart disease, the number-one killer of North Americans, can be caused by the accumulation of cholesterol in the blood vessels. Scientific research on cholesterol has changed direction in recent years. Lipid-rich foods, such as fish and olive oil, were once thought to raise blood cholesterol levels. Currently, most scientists believe that these foods may actually reduce blood cholesterol levels. Similarly, alcohol in moderate consumption may contribute to a decrease in blood cholesterol levels. Added to this confusion is the fact that genes play a major role in determining cholesterol levels. Research indicates that people with a certain genetic makeup are predisposed to atherosclerosis, which is a buildup of cholesterol in the walls of blood vessels that causes narrowing of the vessels (**Figure 9**).

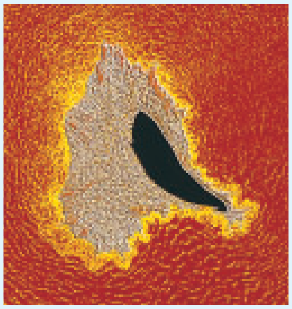

Figure 9
Atherosclerosis (tan area) causes restricted blood flow in blood vessels and can lead to a blockage, possibly causing a heart attack or stroke.

Not all cholesterol is bad. Cholesterol is found naturally in cell membranes and acts as the raw material for the synthesis of certain hormones—sex hormones are made from it.

The cells of the body package cholesterol in water-soluble protein in order to transport it in the blood. Two important types are low-density lipoprotein and high-density lipoprotein.

Low-Density Lipoprotein (LDL)

LDL is considered to be "bad" cholesterol. About 70 % of cholesterol intake is in the form of LDL. High levels of LDL have been associated with the clogging of arteries. LDL particles bind to receptor sites on cell membranes and are removed from the blood (principally by the liver). However, as the level of LDL increases and exceeds the number of receptor sites, excess LDL-cholesterol begins to form deposits in the walls of arteries. The accumulation of cholesterol and other substances in the artery walls is known as plaque. Unfortunately, plaque restricts blood flow and can lead to a heart attack or stroke.

High-Density Lipoprotein (HDL)

HDL is often called "good" cholesterol. HDL carries bad cholesterol back to the liver, which begins breaking it down. HDL lowers blood cholesterol. Most researchers now believe that the balance between LDL and HDL is critical in assessing the risks of cardiovascular disease. Some researchers believe that exercise increases the level of HDL. Strong evidence also supports the theory that fibre, or cellulose, in the diet helps reduce cholesterol. It is believed that fibre binds to cholesterol in the gastrointestinal tract. However, it should be pointed out that fibre does not affect everyone the same way.

Trans Fats

By adding hydrogen molecules to unsaturated fats, such as vegetable oils, manufacturers are able to convert them into more stable saturated fats. This process, known as hydrogenation, is used to convert vegetable oil into margarine or shortening. The word *trans* comes from the transformation of unsaturated fats, with reactive double bonds between carbon atoms, into the more stable, less reactive saturated fats. The process increases the shelf-life of foods.

By increasing the shelf-life of trans fats, manufacturers also make them more difficult for you to break down. Rather than becoming a source of energy, these fats are stored in the body. Trans fats lead to obesity. Scientific evidence shows that the consumption of trans fats and dietary cholesterol raises LDL levels while lowering HDL levels, which increases the risk of heart disease. Many physicians indicate that trans fats are far worse than naturally occurring saturated fats. On November 23, 2004, the House of Commons passed a motion calling for a task force to create a regulation that would limit the trans fat content in all food products. Although no maximum daily intake has been established in Canada, most experts advocate between 1 g and 2 g of trans fats at most. Many North Americans consume as much as 20 g of trans fats per day. It's easy to see how when you look at the following examples:

- Five small chicken nuggets from a fast-food outlet contained nearly 4 g of trans fats.
- An apple danish from a donut shop contained about 2.7 g of trans fats.
- One large serving of French fries contained as much as 6 g of trans fats.

Case Study Questions

1. Doctors recommend that no more than 30 % of your dietary intake be fat. Why should fat consumption be limited?
2. Differentiate between "good" and "bad" cholesterol.
3. The level of LDL in your blood does not solely determine your risk for heart attack.
   (a) What influence do genes have?
   (b) What influence do HDL levels have?
4. What are trans fats? Why are they a reason for concern?
5. Should legislation be introduced to limit trans fats in foods?

Proteins

Unlike carbohydrates and fats, proteins are not primarily energy compounds. **Proteins** are used to form the structural parts of a cell. Whenever cells are damaged and require repair, proteins are manufactured. Your cells also make proteins to build structures for new cells. Proteins are composed of building blocks called **amino acids**. **Figure 10** shows the general structure of an amino acid. The NH_2 group is the amino group, and the COOH group is the carboxyl group. The R group can represent a number of different structures and differentiates one amino acid from another.

Cytoplasmic organelles like the mitochondria and ribosomes are composed largely of protein. The predominant part of muscles, nerves, skin, and hair is protein. Antibodies are specialized proteins that help the body defend itself against disease; enzymes are proteins that speed chemical reactions. Like lipids and carbohydrates, proteins are composed of carbon, hydrogen, and oxygen. However, proteins contain nitrogen and, often, sulfur atoms as well. Like sugars and lipids, proteins can supply energy for the tissues, although energy production is not their main function.

The diversity among people and among different species can, in part, be explained by proteins. A limited number of carbohydrates and lipids are found in all living things, but the array of proteins is almost infinite. Proteins are composed of 20 different amino acids. With a change in position of a single amino acid, the structure of a protein can be altered. The structure of six amino acids is shown in **Figure 11**. A small protein may contain only a few amino acids, while a large one may have more than 250 000 amino acids.

protein a chain of amino acids that form the structural parts of cells or act as antibodies or enzymes

amino acid a chemical that contains nitrogen; can be linked together to form proteins

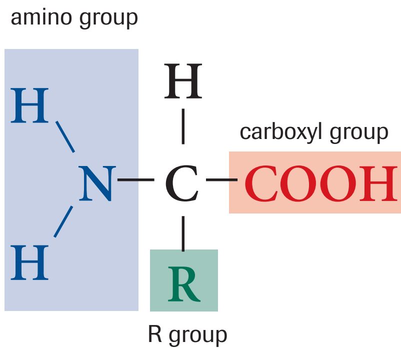

Figure 10
Amino acid structure

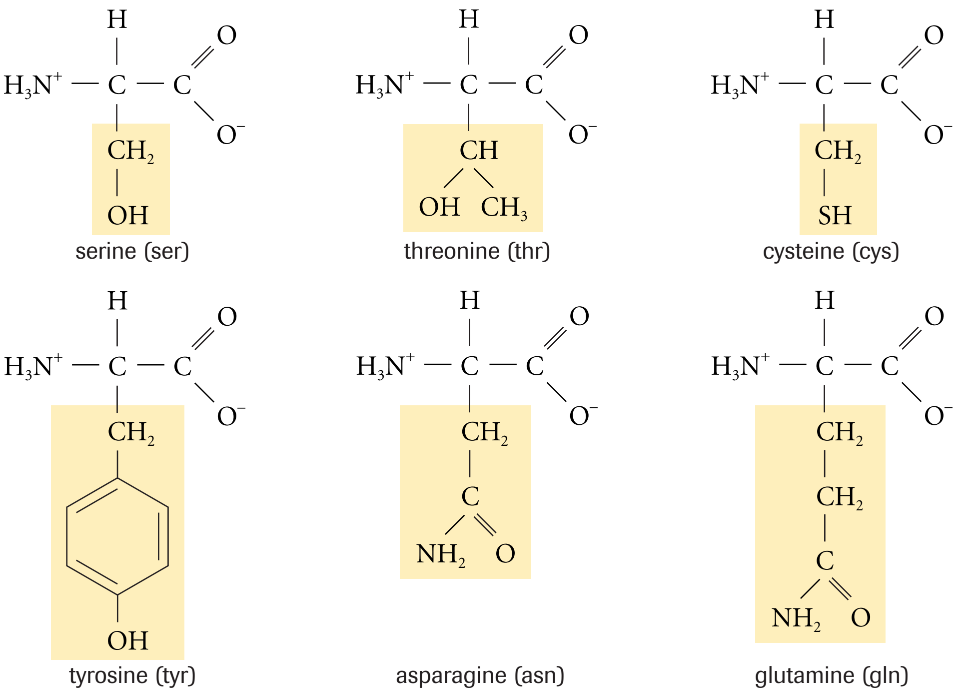

Figure 11
Each amino acid contains an amino and a carboxyl group, which are shown in their ionized form as they would be inside a cell.

The order and number of amino acids determine the type of protein. Fish protein is distinctively different from cow protein and human protein. The protein you eat is digested and absorbed, and the individual amino acids are carried in the blood to the cells of your body. Your cells reassemble the amino acids in sequences that are determined by your genes. **Figure 12** shows how amino acids are joined. As in carbohydrate and lipid synthesis, a water molecule is removed during the synthesis of protein. The covalent bond that forms between the carboxyl group of one amino acid and the amino group of the adjoining amino acid is called a **peptide bond**. For this reason, chains of amino acids are referred to as **polypeptides**.

peptide bond the bond that joins amino acids

polypeptide a chain of three or more amino acids

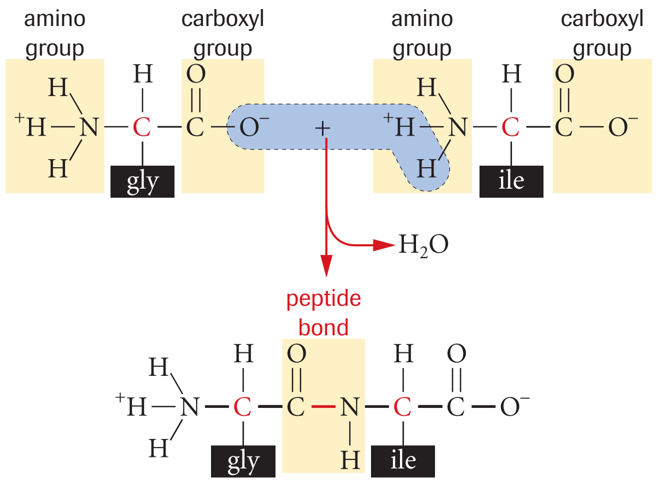

Figure 12
Dehydration synthesis of amino acids to form a polypeptide

The importance of proteins in the diet cannot be overestimated. Although the body is capable of making many of the amino acids, there are eight amino acids that the body cannot synthesize. These are called **essential amino acids** and must be obtained from your food. The lack of any one of the essential amino acids will lead to specific protein deficiencies and disease.

essential amino acid an amino acid that must be obtained from the diet

Structure of Proteins

Proteins are polypeptides that are folded into specific three-dimensional shapes. Some proteins contain more than one polypeptide. A protein's shape, or structure, determines its function. The structure of a protein is determined by its sequence of amino acids. Changing just a single amino acid can alter the structure of a protein. There are four levels of protein structure: primary, secondary, tertiary, and quaternary.

The primary structure of a protein is the unique sequence of amino acids in the chain (**Figure 13 (a)**, next page). British chemist Frederick Sanger was the first to determine the primary structure of a protein. He identified the amino acid sequence of cow insulin. The primary structure of a protein determines its secondary structure. Depending on the amino acids in the polypeptide chain, folds and coils can occur along the length of the chain. These make up the secondary structure. Hydrogen bonding between amino acids pulls the chain into helical coils and pleated sheets (**Figure 13 (b)**, next page).

Additional folding of the polypeptide chain forms the tertiary structure (**Figure 13 (c)**, next page). The tertiary structure occurs because of interactions between the R groups of different amino acids. An example of an R-group interaction is a disulfide bridge. When the sulfur-containing R groups of two cysteine amino acids are close together, they form a bond called a disulfide bridge. A single polypeptide chain of hemoglobin, the iron-containing pigment found in red blood cells, is a tertiary protein structure.

Quaternary proteins are large globular proteins formed from two or more polypeptides (**Figure 13 (d)**, next page). Hemoglobin is a quaternary protein. It contains four individual polypeptide chains that combine to form the functional hemoglobin molecule.

CAREER CONNECTION

Registered Dietician
As many Canadians rely more on fast food, concern has been raised about how diet affects health. Dieticians provide information on how many calories should be consumed and the types of foods needed to maintain health. Investigate career possibilities for registered dieticians.

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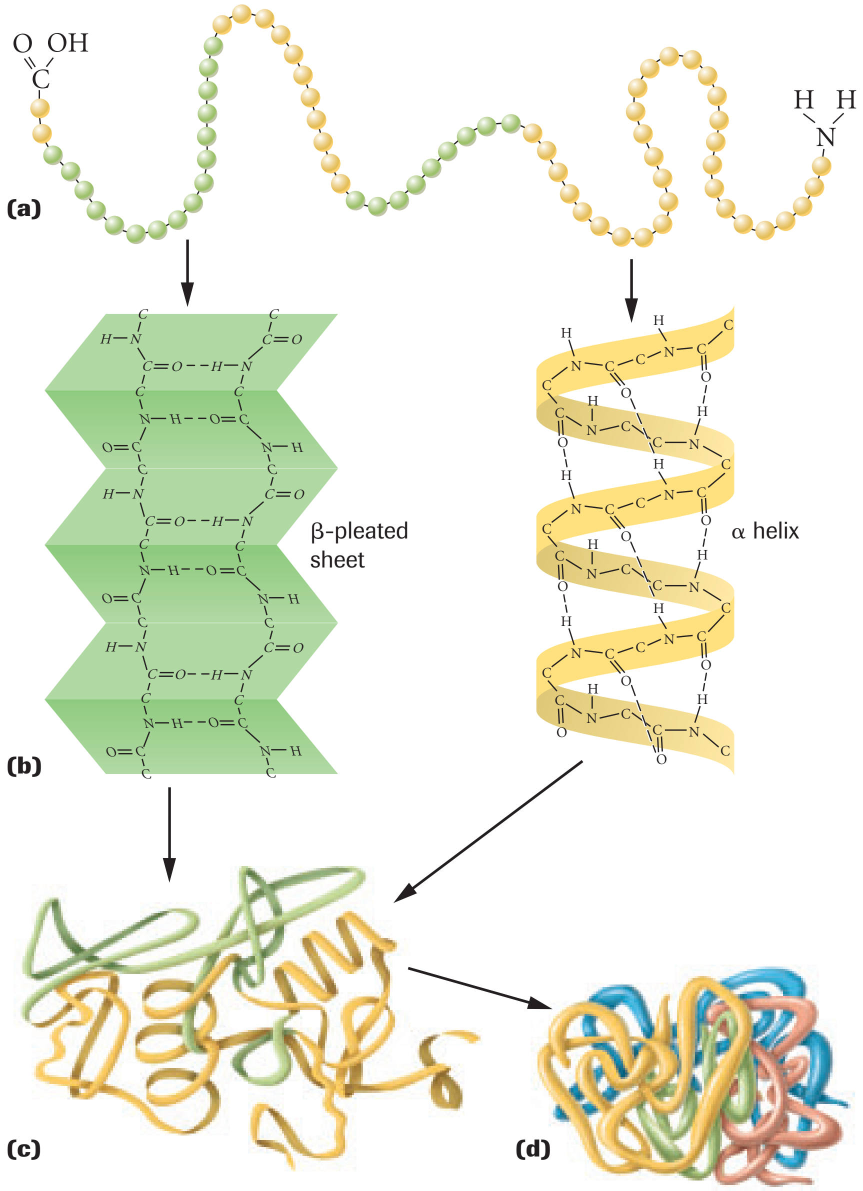

Figure 13
(a) The primary structure of a protein is the sequence of amino acids in the polypeptide strand.
(b) Hydrogen bonds that form with nearby amino acids coil and fold the polypeptide into α helices and β-pleated sheets; these constitute the polypeptide's secondary structure.
(c) The polypeptide folds further to form its tertiary structure. These fold are stabilized by R group interactions.
(d) The clustering of two or more polypeptides in tertiary structure generates the quaternary structure of a protein.

Denaturation and Coagulation

Exposing a protein to excess heat, radiation, or a change in pH will alter its shape. Physical or chemical factors that disrupt bonds cause changes in the configuration of the protein, a process called **denaturation**. The protein may uncoil or assume a new shape. The result is a change in the protein's physical properties as well as its biological activity. Once the physical or chemical factor is removed, the protein may assume its original shape.

A permanent change in protein shape is referred to as **coagulation**. The boiling of an egg, for example, causes the shape of proteins to be altered. The proteins in the egg are said to have coagulated because no matter how much cooling takes place, they will never assume their original shape.

denaturation the process that occurs when the bonds of a protein molecule are disrupted, causing a temporary change in shape

coagulation the process that occurs when the bonds of a protein molecule are disrupted, causing a permanent change in shape

INVESTIGATION 8.2 *Introduction*

Identifying Lipids and Proteins

Lipids and proteins have different chemical compositions, and therefore can be distinguished based on their reaction with certain chemicals. In this investigation, you will use chemical reagents to conduct tests on some common foods and on unknown samples to determine if they contain lipids or proteins.

To perform this investigation, turn to page 272.

Report Checklist

- ● Purpose
- ○ Problem
- ○ Hypothesis
- ● Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

EXPLORE an issue

Issue Checklist

- ○ Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

Irradiation Technology

Food irradiation is a process in which foods are exposed to high levels of radiation to disrupt the DNA of bacteria and other harmful agents growing on the food (**Figure 14**) that could otherwise cause food-borne diseases. This technology is so effective that the food eaten by astronauts is sterilized by irradiation so they do not ingest any microbes that could make them sick while in space.

Irradiation extends the shelf-life of food since food spoilage is caused by bacteria and other microbes. With an extended shelf-life, foods can be transported over greater distances and, consequently, a greater variety of foods are available to consumers at a lower price.

The food does not become radioactive, and the nutritional value that is lost is approximately the same as that lost in cooking. However, it should be noted that the radiation can alter the molecular chemistry of the food, creating radiolytic products. In some studies, benzene and formaldehyde have been identified.

The ionizing energy does create a large number of short-lived free radicals that would be potentially harmful if they persisted, but many experts say they do not. These short-lived free radicals kill microorganisms such as *Salmonella* and inhibit sprouting and ripening in fruits and vegetables. The irradiation of cereal grains kills invading insects that also lead to food contamination and spoilage.

Opponents of radiation technology indicate that some of the new chemical bonds formed in irradiated foods can be harmful, and it is for this reason that they claim the technology should be severely restricted or eliminated completely. In addition, beneficial chemicals, such as vitamins, are often destroyed by the process. Opponents also point out that animals fed irradiated foods have demonstrated various health problems, including premature births, mutations, organ damage, and immune system dysfunction.

Proponents of irradiation technology say that this technology, like traditional methods of preservation, such as salting, canning, and freezing, changes the food only slightly while significantly reducing the spoilage by bacteria.

Despite the many benefits, irradiation is not for all foods. Foods high in fats, such as dairy products and fatty fish, can develop bad odours and tastes because of the breakdown of fat to fatty acids. The technology is much more accepted in North America and Asia, and European governments are more reluctant to use it. At this time, there are no standards for labelling irradiated food.

Figure 14
A technician moves a container of fruit above a pool that is used to study food irradiation. The pool contains an accelerator that produces X-rays.

Statement

Irradiated foods should be allowed.

1. Form a group and research the issue.

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2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statement.
5. Defend your position in the debate.
6. What responsibilities do governments have in regulating irradiation technology?

SUMMARY Essential Nutrients

- Carbohydrates are molecules that contain hydrogen, carbon, and oxygen. Carbohydrates are the preferred source of energy for cells.
- Lipids are compounds formed from glycerol and fatty acids. Lipids are energy-storage compounds.
- Proteins are molecules constructed of amino acids. Proteins are the structural components of cells.

Table 2 Nutrients: An Overview

Nutrient	Sources	Function in humans
carbohydrates	• plants	• energy source
lipids	• plant oils (unsaturated fats) • animal fats (saturated fats)	• energy storage • insulation of skin and cushioning of organs • synthesis of hormones (steroids)
proteins	• plants and animals	• structural components of the cell • enzymes • antibodies

Section 8.1 Questions

1. Provide an example of dehydration synthesis by showing how two monosaccharides form a disaccharide. Show the reactants and end products of the reaction.
2. Explain why marathon runners consume large quantities of carbohydrates a few days prior to a big race.
3. Why is cellulose, or fibre, considered to be an important part of the diet?
4. The following information was gathered by analyzing amino acid sequences of a protein. **Table 3** shows the number of amino acids that are different between two organisms.

Table 3 Amino Acid Differences between Some Organisms

Organism	dog	horse	donkey	pig	duck
dog	-	10	8	4	12
horse		-	1	5	16
donkey			-	4	15
pig				-	13
duck					-

   a) From the information in the table, which two organisms do you think are most closely related? Why?
   b) How similar do you think the amino acids would be between a dog and a fish? Would you expect the amino acids to be more or less similar than those of a dog and a duck? Give your reasons.

5. Using **Figure 15**, identify advantages or disadvantages associated with each of the foods listed.

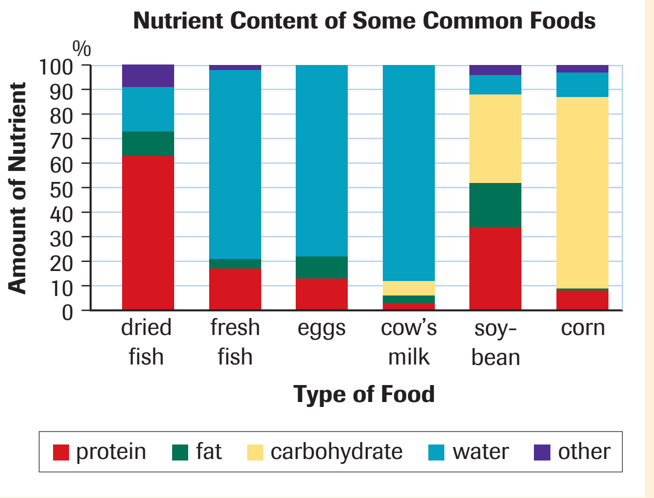

Figure 15

6. A student believes that the sugar inside a diet chocolate bar is sucrose because a test with Benedict's solution yields negative results. How would you go about testing whether or not the sugar present is a nonreducing sugar?

8.2 Enzymes

catalyst a chemical that increases the rate of chemical reactions without altering the products or being altered itself

enzyme a protein catalyst that permits chemical reactions to proceed at low temperatures

substrate a molecule on which an enzyme works

Effect of an Enzyme on Activation Energy

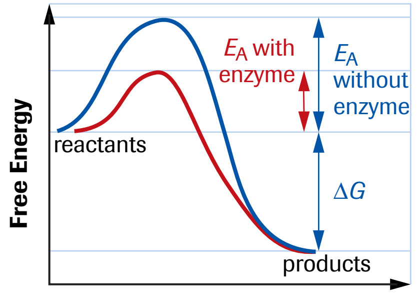

Figure 1
An enzyme decreases the activation energy needed for a reaction to occur.

active site the area of an enzyme that combines with the substrate

cofactor an inorganic ion that helps an enzyme combine with a substrate molecule

coenzyme an organic molecule synthesized from a vitamin that helps an enzyme to combine with a substrate molecule

Molecules are in constant motion. Even molecules in solids vibrate in fixed positions. Although chemical reactions sometimes occur when molecules collide, most reactions do not occur spontaneously. Adding thermal energy to a system increases the system's kinetic energy. This means that the molecules move faster, increasing the number of collisions and the probability of a reaction taking place. However, heating cells is dangerous—too much thermal energy could destroy the cell.

Chemical reactions must proceed at relatively low temperatures within cells. **Catalysts** are chemicals that speed up chemical reactions at low temperatures without altering the products formed by the reaction. The catalyst remains unchanged after the chemical reaction, and so can be used again and again. Reactions that occur within living organisms are regulated by protein catalysts called **enzymes**. Enzymes permit low-temperature reactions by reducing the reaction's activation energy. **Figure 1** compares two energy-releasing reactions—one with an enzyme, and one without.

The molecules on which the enzyme works are called the **substrates**. Each substrate molecule combines with a specific enzyme. The substrate molecules are changed during the reaction, and a product is formed. It has been estimated that about 200 000 different chemical reactions occur within the cells of your body. Each reaction uses a specific enzyme to catalyze it.

Enzymes are identified by the suffix *-ase*, which is added to the name of the substrate that the enzyme combines with. Carbohydrases break down carbohydrates; for example, the enzyme that controls the hydrolysis of sucrose into its two component parts—glucose and fructose—is called sucrase. Proteases break down proteins, while lipases act on lipids.

Enzymes increase the probability of reactions occurring by bringing substrate molecules together. Enzymes have folded surfaces that trap particular substrate molecules, aligning them to cause the chemical reaction. Having large molecules collide is not enough—the molecules must collide at the appropriate binding sites if the reaction is to proceed.

The **active site** of the enzyme is the area that joins with the substrate molecules. Each enzyme has a specially shaped active site that provides a "dock" for specific substrate molecules. This long-standing model, called the "lock-and-key model," was first proposed by Emil Fischer in 1890. The temporary joining of the enzyme with the substrate forms the enzyme-substrate complex (**Figure 2**).

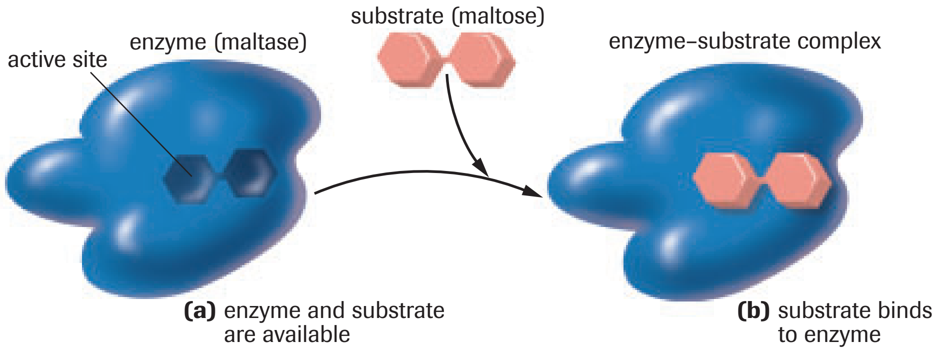

Figure 2
The enzyme maltase binds to maltose, its substrate.

A modified theory, called the "induced-fit model," replaced the lock-and-key model in 1973. The induced-fit model suggests that the actual shape of the active site is altered slightly when the substrate molecules are trapped, making the fit between enzyme and substrate even tighter during the formation of the enzyme-substrate complex (**Figure 2** , previous page).

Some enzymes require **cofactors** or **coenzymes** to help them bind to substrate molecules. Cofactors are inorganic ions such as iron, zinc, and potassium, as well as copper-containing compounds. Coenzymes are organic molecules that are synthesized from vitamins. Coenzymes and some cofactors may work with more than one enzyme.

Factors Affecting Enzyme Reactions

It has been estimated that a single enzyme can catalyze between 100 reactions and 30 million reactions every minute. Why do some reactions occur much faster than others? To compare reaction rates, you must examine the different factors that affect enzymes.

pH

The graph in **Figure 3** indicates that enzymes function best within certain pH ranges. The enzyme pepsin, shown in green, operates best in an acidic condition. Not surprisingly, this enzyme is found in the stomach, an area of low pH. The second enzyme, trypsin, shown in blue, is most effective in a basic medium. Not surprisingly, trypsin is found in the small intestine, an area that is generally about pH 9.

To understand why pH affects enzyme activity, you must look at the molecular structure of the protein molecule. Remember that the folds in the protein molecule are created by hydrogen bonds between negatively charged acid groups and positively charged amino groups. The addition of positively charged H^+ ions, characteristic of an acidic solution, or the introduction of negatively charged OH^- ions, characteristic of a basic solution, will affect the hydrogen bonds. Thus, the three-dimensional shape of an enzyme is altered by a change in pH. When the folds in the protein are changed, the active site of the enzyme is transformed, altering the reaction.

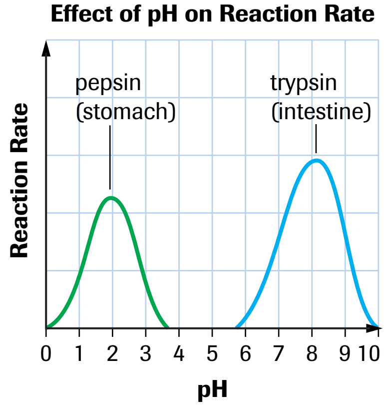

Figure 3
Different enzymes function within different pH ranges.

Substrate Molecule Concentration

Enzyme activity can also be affected by the concentration of substrate molecules. For chemical reactions, the greater the number of substrate molecules, the greater the number of collisions, and the greater the rate of the reaction. Up to a point, enzyme-catalyzed reactions behave in the same manner. The reaction rate shown in **Figure 4** begins to level off at point X because there is a limit to the amount of enzyme available. Substrate molecules cannot join with the active site of an enzyme until it is free. Once the number of substrate molecules exceeds the number of enzyme molecules, the excess substrate molecules will not gain access to the active site of an enzyme. Therefore, the reaction rate begins to level off.

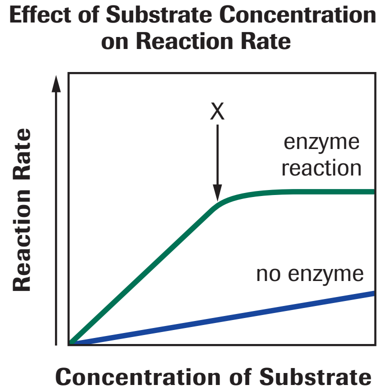

Figure 4
A higher concentration of substrate molecules increases the reaction rate.

Temperature

The graph in **Figure 5** indicates how temperature affects enzyme-catalyzed reactions. The fact that reaction rates increase as the temperature increases should not be surprising. As energy is added, the molecules begin to move faster. The faster the molecules move, the greater the number of collisions. Subsequently, more collisions cause a greater number of products to be formed. But why do reaction rates in our cells peak at about 37 °C and then drop, even though the molecules are moving faster and colliding more often?

To answer this question, recall some important facts about enzymes. The fact that enzymes are proteins is particularly significant because at high temperatures, proteins change shape or are denatured. Any change in enzyme shape will have an effect on the formation of the

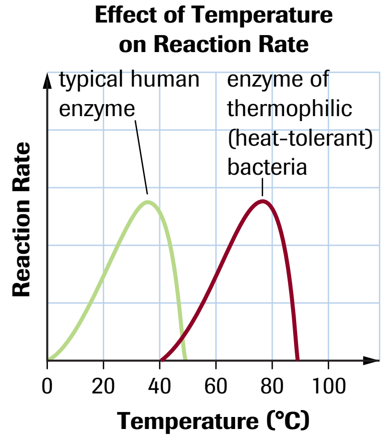

Figure 5
Different enzymes function within different temperature ranges.

enzyme-substrate complex. The greater the change to the active site of the enzyme, the less effective the enzyme. Once the enzyme is denatured, the active site is so severely altered that the substrate can no longer bind with the enzyme. The reaction is no longer catalyzed by the enzyme and, therefore, proceeds at a much slower rate.

The effect of temperature on enzymes helps explain why high fevers can be so dangerous. The relationship between temperature and enzyme-catalyzed reactions also indicates some of the advantages of being a homeotherm, an animal that maintains a constant body temperature. Mammals, birds, and other homeotherms keep their bodies at optimal temperatures for reactions.

Competitive Inhibition

competitive inhibitor a molecule with a shape complementary to a specific enzyme that competes with the substrate for access to the active site of the enzyme and blocks chemical reactions

Inhibitor molecules can affect enzyme reactions. Often referred to as **competitive inhibitors**, these molecules have shapes very similar to that of the substrate. The inhibitors actually compete with the substrate molecules for the active sites of the enzymes (**Figure 6**). As long as the inhibitors remain joined to the enzyme, the substrate cannot bind, and the enzyme cannot function properly.

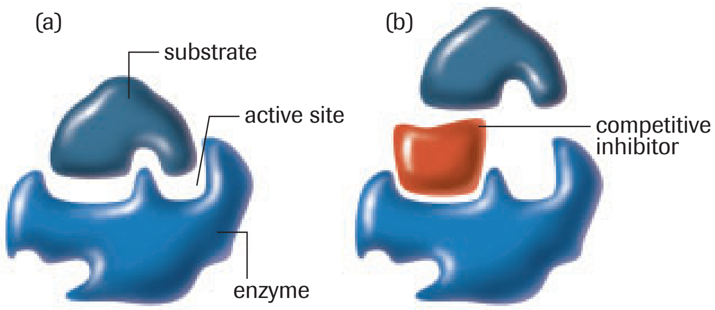

Figure 6
(a) The substrate normally binds to the active site.
(b) A competitive inhibitor competes with the substrate for the active site.

INVESTIGATION 8.3 *Introduction*

Factors That Affect the Catalase Enzyme Reaction

Catalase is an enzyme found in many species that live in oxygen-rich environments. Catalase breaks down hydrogen peroxide (H_2O_2), a toxin. What factors affect the rate of catalase activity?

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

To perform this investigation, turn to page 274.

Regulation of Enzyme Activity

Metabolic pathways are orderly sequences of chemical reactions, with enzymes regulating each step of the reaction. Consider the following example of a metabolic pathway. Testosterone is a male sex hormone synthesized from cholesterol or other steroids. The hormone, which is produced in larger quantities from puberty onward, is responsible for the development of secondary male sex characteristics.

Can you imagine what would happen if all of the steroids in the body were converted into testosterone? The regulation of chemicals produced by metabolic pathways is essential. The production of chemicals within a cell is regulated by the need for those chemicals. As the product from a series of chemical reactions begins to accumulate within a cell, the product interferes with one of the enzymes in a process known as **feedback inhibition**. The interference slows the reaction rate, preventing the accumulation of final products. The final product of the metabolic pathway interferes with the enzyme by combining with its regulatory site. The binding

feedback inhibition the inhibition of an enzyme in a metabolic pathway by the final product of that pathway

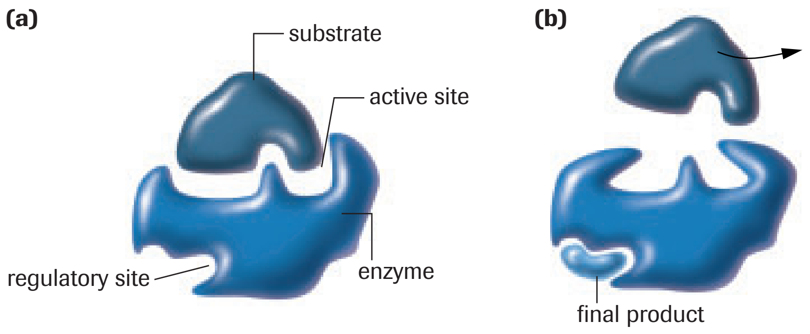

Figure 7
(a) The substrate can bind to the active site.
(b) The final product attaches to the regulatory site and changes the shape of the enzyme so that the substrate can no longer bind.

of the final product with the regulatory site of the enzyme alters the active site, and thus prevents the union of the enzyme and substrate (**Figure 7**).

Regulatory sites are not just used to turn off metabolic pathways. A buildup of the initial substrate can turn on enzyme activity. If the substrate molecule combines at the regulatory site of one of the enzymes, **precursor activity** occurs. During precursor activity, the combination of the substrate and enzyme actually improves the fit of the enzyme-substrate complex. This speeds up the formation of final products. Both feedback inhibition and precursor activity involve the binding of a molecule with the regulatory site of the enzyme. Both processes are called **allosteric activity**. The binding of the final product with the regulatory site of the enzyme will change the enzyme's active site, thereby inhibiting subsequent reactions. The binding of one of the initial reactants with the regulatory site will help mould the active site of the enzyme, improving the fit between substrate and enzyme. **Figure 8** summarizes these processes.

precursor activity the activation of the last enzyme in a metabolic pathway by the initial substrate

allosteric activity a change in an enzyme caused by the binding of a molecule

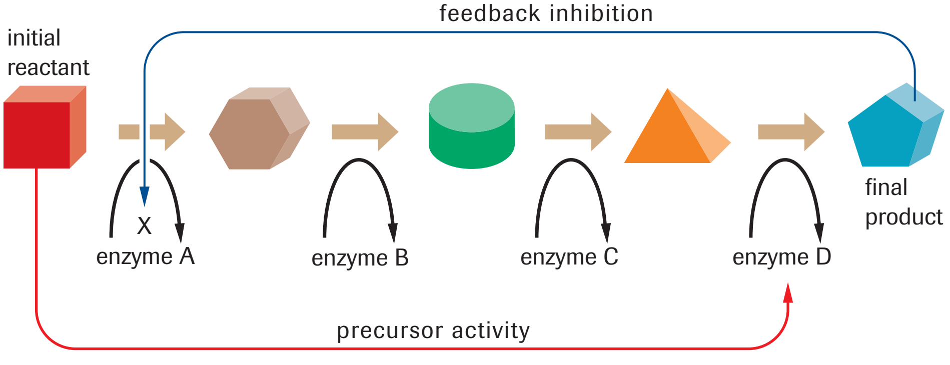

Figure 8
Allosteric activity involves both precursor activity and feedback inhibition. Precursor activities turn metabolic pathways "on," while feedback inhibition activities turn metabolic pathways "off."

SUMMARY *Enzymes*

- Chemical reactions within cells are regulated by enzymes. Enzymes are protein catalysts that lower activation energy and permit chemical reactions to proceed at body temperature.
- Cofactors are inorganic ions that help enzymes combine with substrate molecules. Coenzymes are organic molecules that help enzymes combine with substrate molecules.
- A competitive inhibitor has a shape complementary to a specific enzyme, thereby permitting it access to the active site of the enzyme. Inhibitors block chemical reactions.

- Feedback inhibition is the inhibition of the first enzyme in a metabolic pathway by the final product of that pathway.
- Precursor activity is the activation of the last enzyme in a metabolic pathway by the initial substrate.

Section 8.2 Questions

1. Explain the importance of enzymes in metabolic reactions.
2. How do enzymes increase the rate of reactions?
3. List and explain four factors that affect the rate of chemical reactions.
4. How do cofactors and coenzymes work?
5. What are competitive inhibitors?
6. What is allosteric activity?
7. How are metabolic pathways regulated by the accumulation of the final products of the reaction?
8. Explain how enzymes work in the lock-and-key model. How has the induced-fit model changed the way in which biochemists describe enzyme activities?
9. Use the metabolic pathway in **Figure 9** to explain feedback inhibition.
10. Use **Figure 10** to answer the following questions.
    (a) Match labels A, B, and C in the diagram to the following: reactants, products, and activation energy.
    (b) How will decreasing the number of substrate molecules affect the rate of reaction? Explain your answer.
    (c) If an enzyme is introduced into this chemical reaction, explain how the reaction curve would change.
11. The reaction shown in **Figure 11** is catalyzed by an enzyme.
    (a) Complete the graph by showing what would happen if a competitive inhibitor was added at "T."
    (b) Explain why the inhibitor would affect the rate of the chemical reaction.
12. Using the information that you have gained about enzymes, explain why high fevers can be dangerous.

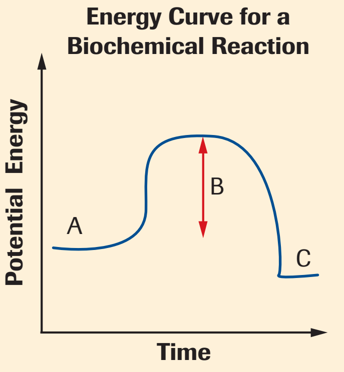

Figure 10

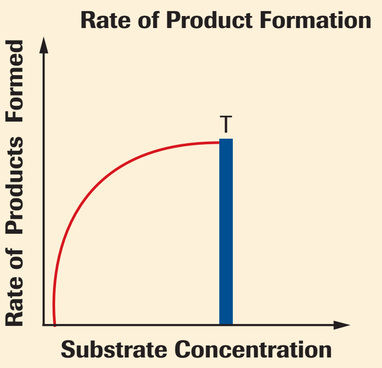

Figure 11

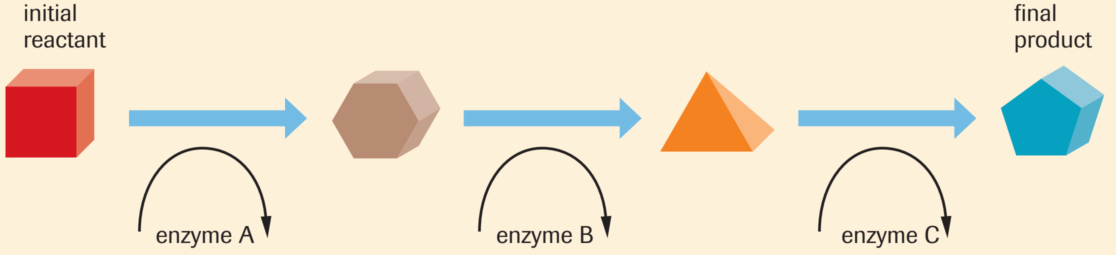

Figure 9

Ingestion 8.3

There are four components of the digestive process:

1. ingestion—the taking in of nutrients
2. digestion—the breakdown of complex organic molecules into smaller components by enzymes
3. absorption—the transport of digested nutrients to the cells of the body
4. egestion—the removal of food waste from the body

The digestive tract of adult humans, normally 6.5 m to 9 m long, stores and breaks down organic molecules into simpler components. **Figure 1** shows the entire digestive system. Physical (mechanical) digestion begins in the mouth, where food is chewed and formed into a bolus (the Greek word for ball) by the tongue. Physical digestion breaks food into smaller pieces, increasing the surface area for chemical digestion.

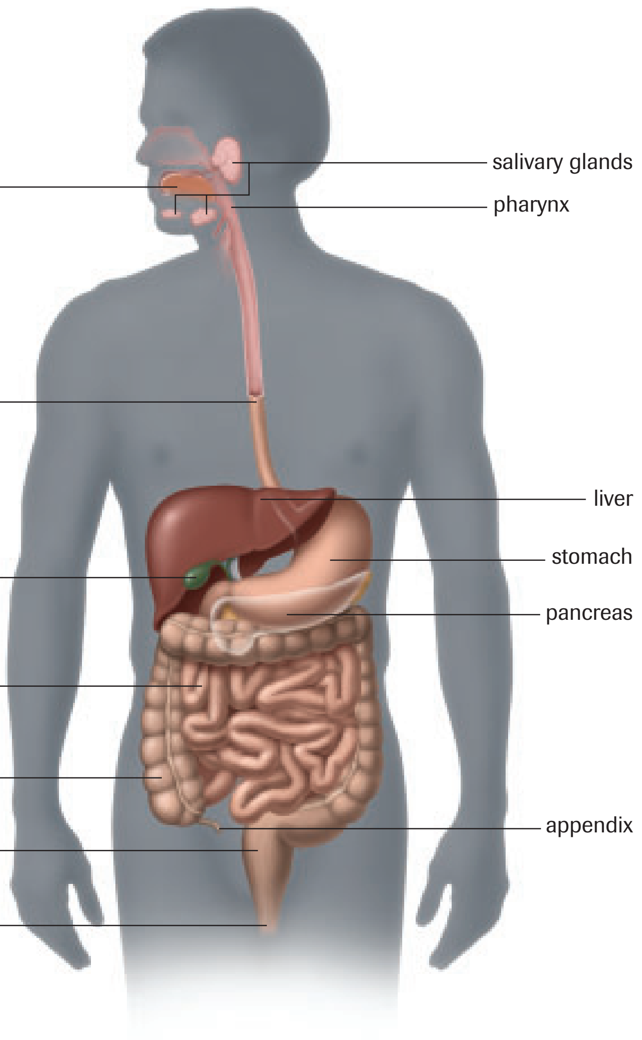

Figure 1
The human digestive system and accessory organs

CAREER CONNECTION

X-ray Technician

X-ray technicians perform various functions, such as advising patients how to prepare for X rays and ensuring that the X ray is taken safely. X-ray technicians need to know the fundamentals of anatomy, disease, and how trauma affects various organ systems. Research the programs available for certification as an X-ray technician.

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amylase an enzyme that breaks down complex carbohydrates

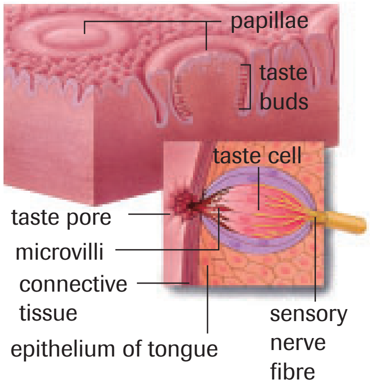

Figure 2
Taste buds are located along the tongue.

Salivary Glands

Saliva, the watery fluid produced by the salivary glands, contains **amylase** enzymes, which break down starches (complex carbohydrates) to simpler carbohydrates. Saliva dissolves food particles and makes it possible to taste what is being eaten. It also lubricates the food so that it can be swallowed.

We detect the flavour when food particles dissolved in saliva penetrate the cells of the taste buds located on the tongue and cheeks. (Our sense of smell is also involved in tasting food.) Different types of receptors respond to specific flavours. For example, the taste buds are equipped with receptors (**Figure 2**) that have a specific geometry that permits the identification of sweet tastes from carbohydrates. Nerve cells for taste are stimulated when receptor sites are bound by chemical compounds with a complementary shape. Try dissolving foods in saliva by drying your tongue and then placing a few grains of salt on it. You will not detect any flavour until the crystals dissolve in your saliva.

Teeth

The teeth are important structures for physical digestion (**Figure 3**). Eight chisel-shaped teeth at the front of your mouth, called incisors, are specialized for cutting. The incisors are bordered by sharp, dagger-shaped canine teeth that are specialized for tearing. Next to the canine teeth are the premolars. These broad, flattened teeth are specialized for grinding. The molars are next. These teeth tend to be even broader and have cusps that are even more flattened. They are designed for crushing food. The last set of molars are the wisdom teeth, so called because they usually do not emerge until we reach about 16 to 20 years of age. Each tooth is covered with enamel, which is the hardest substance in the human body.

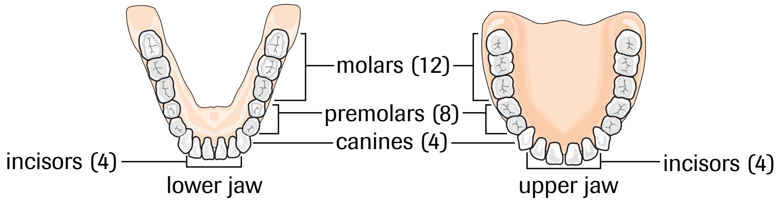

Figure 3
Human adult teeth

peristalsis rhythmic, wavelike contractions of muscle that move food along the gastrointestinal tract

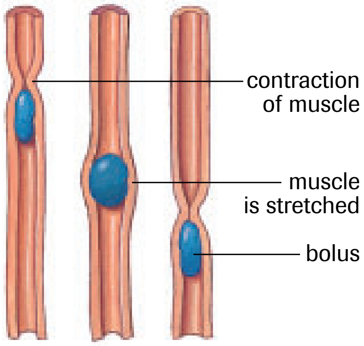

Figure 4
Rhythmic contractions of muscle move food along the digestive tract.

Esophagus

Once swallowed, food travels from the mouth to the stomach by way of the esophagus. The bolus of food stretches the walls of the esophagus, activating muscles that set up waves of rhythmic contractions called **peristalsis**. Peristaltic contractions, which are involuntary, move food along the gastrointestinal tract (**Figure 4**). The only points at which food is moved voluntarily along the tract is during swallowing and during the last phase, egestion. Peristaltic action will move food or fluid from the esophagus to the stomach even if you stand on your head.

Practice

1. What are the functions of saliva?
2. How does chewing assist in the digestion of food?
3. What are amylase enzymes and why are they necessary?
4. How is food moved along the esophagus?

Stomach

The stomach is the site of food storage and initial protein digestion. The stomach contains three layers of muscle, which run in different directions so that the muscle contractions can churn the food (**Figure 5 (a)**).The movement of food to and from the stomach is regulated by circular muscles called **sphincters**. Sphincters act like the drawstrings on a bag. Contraction of the lower esophageal sphincter (LES) closes the opening to the stomach, while its relaxation allows food to enter. The LES prevents food and acid from being regurgitated up into the esophagus. A second sphincter, the pyloric sphincter, regulates the movement of food and stomach acids into the small intestine (**Figure 5 (b)**).

sphincter a constrictor muscle that regulates the opening and closing of a tubelike structure

EXTENSION

Activation of Digestive Zymogens

What are digestive zymogens? This Audio Clip will give you information on a number of protein-digesting enzymes that are secreted into the stomach and duodenum, and unravel the mechanism of how they are activated from a zymogen state.

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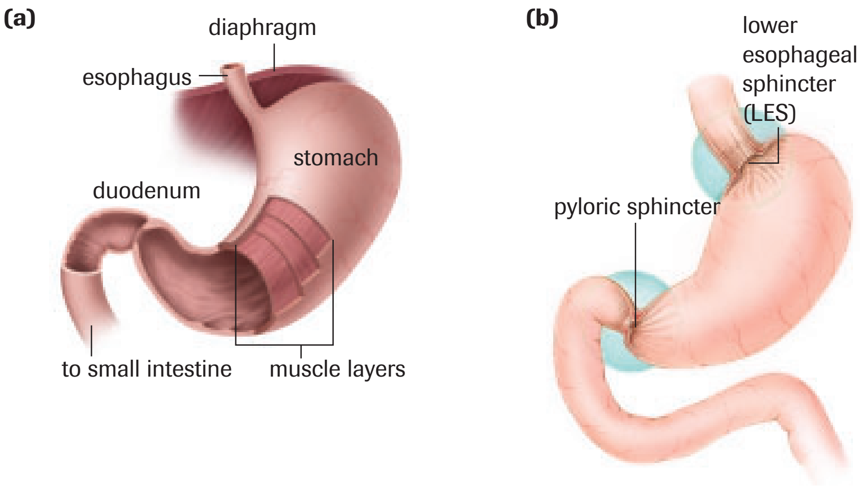

Figure 5
(a) Muscle is responsible for the contractions of the stomach.
(b) Sphincters regulate the movement of food.

The J-shaped stomach has numerous ridges that allow it to expand so that it can store about 1.5 L of food. Millions of cells line the inner wall of the stomach. These cells secrete the various stomach fluids, called gastric fluids or gastric juice, that aid digestion. Contractions of the stomach mix the food with the gastric fluids. Therefore, the stomach is involved in both physical and chemical digestion. Approximately 500 mL of these fluids are produced following a large meal. Gastric fluid includes **mucus**, hydrochloric acid (HCl), pepsinogens, and other substances. Hydrochloric acid kills many harmful substances that are ingested with food. It also converts pepsinogen into its active form, **pepsin**, which is a protein-digesting enzyme. Pepsin breaks the long amino acid chains in proteins into shorter chains, called polypeptides.

mucus a protective lubricating substance composed mostly of protein

pepsin a protein-digesting enzyme produced in the stomach

The pH inside the stomach normally ranges between 2.0 and 3.0, but may approach pH 1.0. Acids with a pH of 2.0 can dissolve fibres in a rug! It is the high acidity of hydrochloric acid that makes it effective at killing pathogens and allows pepsin to do its work. How does the stomach safely store these strong chemicals, both of which dissolve the proteins that make up cells? A layer of alkaline mucus protects the stomach lining from being digested. Pepsinogen moves through the cell membrane and mucous lining, is activated by HCl, and becomes pepsin. The pepsin breaks down the proteins in the food, but not the proteins of the stomach's cells because these proteins are protected by the mucous layer. The esophagus does not have a protective mucous layer, so if the LES is weak, stomach acid may enter the esophagus and damage its lining. This causes the pain known as heartburn.

DID YOU KNOW ?

How Big Is Your Stomach?

The stomach capacity of a newborn human baby can be as little as 60 mL. An adult stomach has a maximum capacity of about 1.5 L, while the stomach of a cow is divided into four compartments and may hold up to 300 L.

ulcer a lesion on the surface of an organ

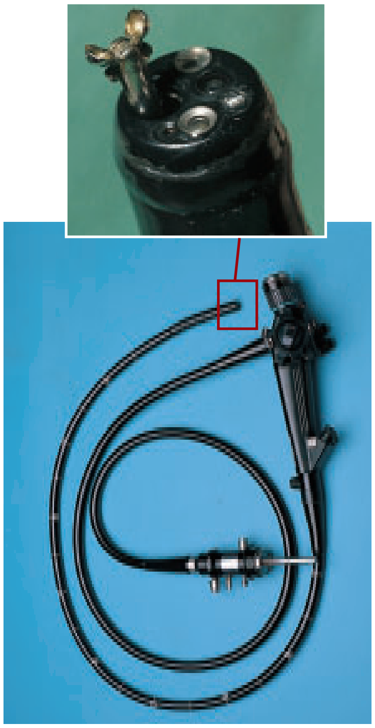

Figure 6
The endoscope can be used to look inside the body.

Peptic Ulcers

When the protective mucous lining of the stomach breaks down, the cell membrane is exposed to the HCl and pepsin. The destruction of the cell membrane leads to a peptic **ulcer**. Beneath the thin layer of cells is a rich network of blood vessels. As the acids irritate the cells of the stomach lining, there is an increase in blood flow and acid secretions. With this increased blood flow and acid secretion, more tissue is burned, and the cycle continues. Eventually the blood vessels begin to break down.

Most ulcers are the result of an infection by a bacterium called *Helicobacter pylori (H. pylori)*. Dr. Barry Marshall, an Australian physician, first made this connection in the early 1980s. Scientists were initially skeptical of Dr. Marshall's findings, since it was believed that bacteria would be unable to survive the highly acidic conditions of the stomach. In 2005, Dr. Marshall received a Nobel Prize in Physiology or Medicine for his work with *H. pylori* and ulcers. A simple breath test for the presence of *H. pylori* is now widely available. Dr. Marshall is currently working in the United States, where he is investigating a possible link between the microbe and some forms of stomach cancer.

If an *H. pylori* infection is found early enough, treatment with an antibiotic can cure the ulcer. In some cases, the amount of damage is severe enough to also require surgery. A device called an endoscope can be fitted with a light-emitting glass fibre and then positioned inside a patient's body (**Figure 6**). Physicians then use the endoscope to view the damage. Tiny forceps fitted in the endoscope may be used to extract small pieces of tissue for a biopsy. Special lasers designed for surgical applications may be used to remove any damaged tissue. The laser beam is thinner than most scalpels and provides the added advantage of sealing small blood vessels.

EXPLORE *an issue*

Issue Checklist

- ○ Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

Fad Diets

Dieting is big business. An array of low-calorie food products and specialized diet plans are competing in an ever-expanding market. Diet plans like the Atkins Diet are high in protein and low in carbohydrates, while the Beverly Hills Diet recommends low protein and high carbohydrate consumption. Some weight-loss plans include appetite suppressants such as amphetamines, as well as laxatives.

People who are overweight are more prone to certain diseases such as atherosclerosis and diabetes; however, being underweight can also cause problems, such as fatigue and increased risk of illness and injury.

Statement
Specialized diet plans may actually contribute to malnutrition in people who use them consistently.

Point
Some diets emphasize high-calorie fatty foods such as steaks, cheese, and milk, which can increase cholesterol levels. Liquid protein diets provide only about 400 calories per day, whereas most people need about 1200 calories per day.

Counterpoint
Low-calorie, nonfattening foods are carefully monitored by nutritionists. Prepared products are not the only answer to good eating. People must take responsibility for maintaining a healthy balance in their food intake. Dieting alone cannot be expected to perform miracles.

1. Research the issue.

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2. Reflect on your findings. Discuss the various viewpoints with others.
3. Prepare for the class debate.

WWW WEB Activity

Web Quest—What Are You Eating?

Have you ever explored the intake and output of energy in your own body? This Web Quest guides you through collecting data on your own food intake and physical activity. Using this information, you can then analyze the data and find out exactly what is happening with calories coming in and going out of your own body!

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SUMMARY Ingestion

- Saliva contains amylase enzymes that initiate carbohydrate breakdown, and it dissolves food particles, activates the taste buds, and lubricates the food.
- Teeth bite, tear, grind, and crush food into smaller particles.
- After food is swallowed, movement through the esophagus is regulated by peristalsis, contractions of muscle.
- Sphincter muscles regulate the movement of food into and out of the stomach.
- Digestive fluids in the stomach include hydrochloric acid (HCl), pepsinogens, and mucus. HCl kills pathogens and helps convert pepsinogen into pepsin. Pepsin digests proteins. Mucus protects the stomach from the above two fluids.

EXTENSION

Dying To Be Thin
For some young people, the conflict between real and fashionable images of the body can lead to an eating disorder. In severe cases, eating disorders such as anorexia can cause low blood pressure, bone loss, damage to the kidneys, liver and heart, and even death. This is a *NOVA* video.

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Section 8.3 Questions

1. How are the digestive system and other organ systems interdependent?
2. Differentiate between physical and chemical digestion. Provide examples of each.
3. Is the movement of food through your digestive system voluntary or involuntary? What mechanisms are responsible for moving food along the gastrointestinal tract?
4. The type of teeth that a mammal has is matched to diet. Keeping in mind the function of different types of teeth, name an animal that would have well-developed (a) canines, and (b) molars and premolars.
5. How is movement of food into and out of the stomach regulated?
6. What substances make up gastric fluid?
7. What is the function of the mucous layer that lines the stomach?
8. What is an endoscope and why is it useful?
9. List and discuss two factors that affect enzyme activity. Provide two examples.
10. State the functions of the enzymes amylase and pepsin.
11. What are two factors that contribute to stomach ulcers?
12. In stomach cells, protein-digesting enzymes are stored in the inactive form. Once the enzymes leave the stomach, an acid in the stomach changes the shape of the inactive enzyme, making it active. The active enzyme begins to digest proteins. Why must protein-digesting enzymes be stored in the inactive form?
13. Where would you expect to find digestive enzymes that function best at a pH of 2.0? at a pH of about 7.0?
14. Why does the low pH of the stomach stop the starch digestion that begins in the mouth? What is the advantage to the body of this delay?
15. Would a mouth with a pH of 5.0 have more or less tooth decay than a mouth with a pH of 7.0? Why?
16. Find out about the different kinds of ulcers. Learn about the risk factors, symptoms, and treatments.

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17. Heartburn, or acid indigestion, occurs when stomach acids back up into the esophagus, burning its lining. Antacids can be taken to reduce the burning sensation. How might using antacids to mask the pain of heartburn inadvertently lead to more serious problems?

8.4 Digestion

CAREER CONNECTION

Health Service Administrator
These health professionals direct and evaluate health programs and plans. Health service administrators have opportunities to work in a wide range of fields, including medicine, pharmacy, accounting, and management. If you are interested in medical service and administration, explore this career further.

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Most chemical digestion takes place in the small intestine, so named because of its narrow diameter. In humans, the small intestine is up to 7 m in length, but only 2.5 cm in diameter (**Figure 1**). The large intestine, by comparison, is only 1.5 m in length, but 7.6 cm in diameter. In mammals, the length of the small intestine is related to diet. Meats are relatively easy to digest, while plant materials are more difficult to digest. Accordingly, carnivores, such as wolves and lions, have short small intestines while herbivores, such as rabbits, have long small intestines. Omnivores, such as raccoons, pigs, bears, and humans, have small intestines that are of intermediate length, allowing them to digest both types of food.

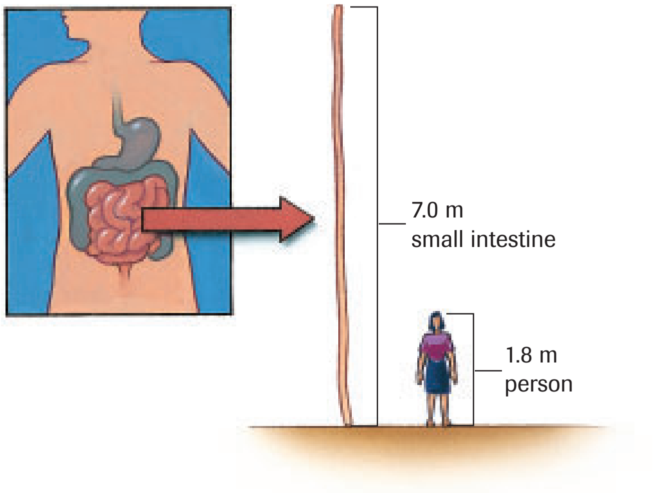


Figure 1
A comparison of the length of the small intestine to the height of a person

Small Intestine

The majority of digestion occurs in the first 25 cm to 30 cm of the small intestine, an area known as the **duodenum**. The second and third components of the small intestine are called the jejunum and the ileum. The small intestine secretes digestive enzymes and moves its contents along by peristalsis.

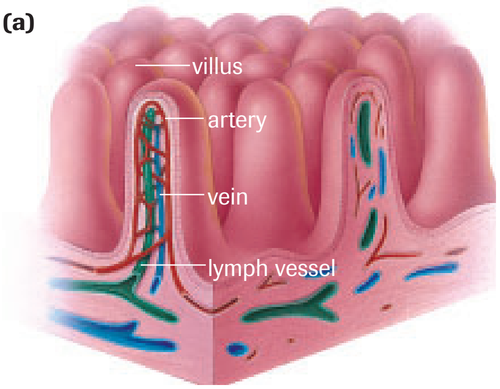
duodenum the first segment of the small intestine

The stomach absorbs some water, specific vitamins, some medicines, and alcohol, but most absorption takes place within the small intestine. Long fingerlike projections called **villi** (singular: villus) greatly increase the surface area of the small intestine (**Figure 2 (a)**). One estimate suggests that villi account for a tenfold increase in surface area for absorption. The cells that make up the lining of each villus have **microvilli**, which are fine, threadlike extensions of the membrane that further increase the surface for absorption (**Figure 2 (b)**).

villi small, fingerlike projections that extend into the small intestine to increase surface area for absorption

microvilli microscopic, fingerlike projections of the cell membrane

(a)



(b)

Figure 2
(a) Blood and lymph vessels of a villus
(b) Microvilli

Each villus is supplied with a **capillary** network that intertwines with lymph vessels called **lacteals** that transport materials. Some nutrients are absorbed by diffusion, but some nutrients are actively transported from the digestive tract. Monosaccharides and amino acids are absorbed into the capillary networks; fats are absorbed into the lacteals.

capillary a blood vessel that connects arteries and veins; the site of fluid and gas exchange

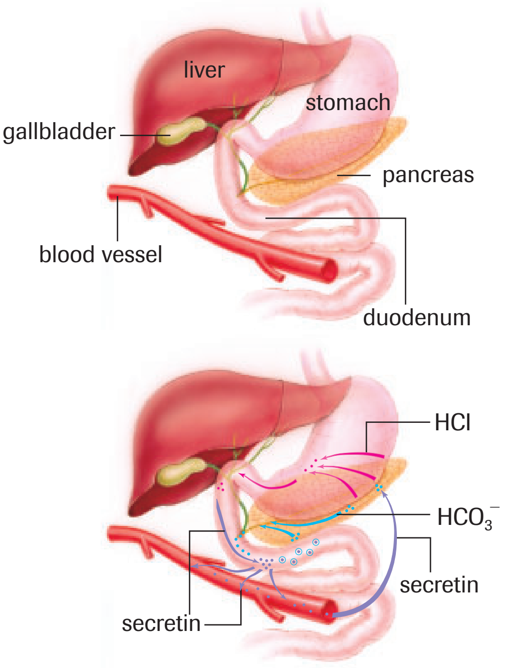
lacteal a small vessel that transports the products of fat digestion to the circulatory system

Pancreas

As you already know, food moves from the stomach to the small intestine. Partially digested food reaches the small intestine already soaked in HCl and pepsin. How are the cells of the small intestine protected? To answer this question, you must look beyond the small intestine to the pancreas.

When acids enter the small intestine, a chemical called prosecretin is converted into **secretin**. Secretin is absorbed into the bloodstream and carried to the pancreas, where it signals the release of a solution containing bicarbonate ions. Bicarbonate ions (HCO_3^-) are released from the pancreas and carried to the small intestine, where they buffer the HCl in gastric fluid and raise the pH from about 2.5 to 9.0. The basic pH inactivates pepsin. Thus, the small intestine is protected from stomach acids by the release of secretin. These steps are summarized in **Figure 3**.

secretin a hormone released from the duodenum that stimulates pancreatic and bile secretions



- HCl enters the duodenum from the stomach.
- HCl stimulates the conversion of prosecretin into secretin.

$$\underset{\text{(inactive form)}}{\textbf{prosecretin}} \xrightarrow{\textbf{HCl}} \underset{\text{(active form)}}{\textbf{secretin}}$$

- Secretin is aborbed into the blood vessels.

- Secretin is carried by the circulatory system to the pancreas.
- Here secretin acts as a chemical messenger, stimulating the release of pancreatic fluids.
- The HCO_3^- ions, released by the pancreas, neutralize the HCl from the stomach. The neutralization of acid protects the lining of the duodenum.

Figure 3
The function of secretin

The pancreatic secretions also contain enzymes that promote the breakdown of the three major components of food: proteins, carbohydrates, and lipids. A protein-digesting enzyme, called trypsinogen, is released from the pancreas. Once trypsinogen reaches the small intestine, an enzyme called **enterokinase** converts the inactive trypsinogen into **trypsin**, which acts on the partially digested proteins. Trypsin breaks down long-chain polypeptides into shorter-chain peptides.

A second group of enzymes, the **erepsins**, are released from the pancreas and small intestine. They complete protein digestion by breaking the bonds between short-chain peptides, releasing individual amino acids (**Figure 4**, next page).

The pancreas also releases amylase enzymes, which continue the digestion of carbohydrates begun in the mouth by salivary amylase. The intermediate-size chains are broken down into disaccharides. The small intestine releases disaccharide enzymes, called disaccharidases, which complete the digestion of carbohydrates.

enterokinase an enzyme of the small intestine that converts trypsinogen to trypsin

trypsin a protein-digesting enzyme

erepsin an enzyme that completes protein digestion by converting short-chain peptides to amino acids

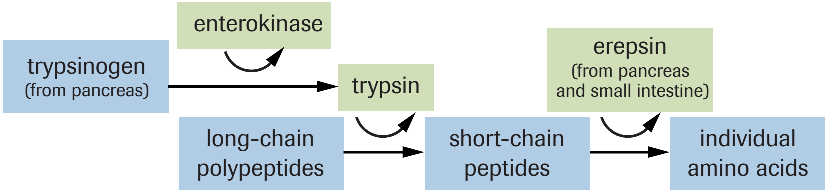


Figure 4
Breakdown of proteins in the small intestine

lipase a lipid-digesting enzyme

Lipases are enzymes released from the pancreas that break down lipids (fats). There are two different types of lipid-digesting enzymes. Pancreatic lipase, the most common, breaks down fats into fatty acids and glycerol. Phospholipase acts on phospholipids.

For a summary of the enzymes found in the small intestine, where they are produced, and the reactions that take place, see **Table 1**.

Table 1 Digestion in the Small Intestine

Enzyme	Produced by	Reaction
lipase	pancreas	fat droplets + H_2O → glycerol + fatty acids
trypsin	pancreas	protein + H_2O → peptides
erepsin	pancreas, small intestine	peptides + H_2O → amino acids
pancreatic amylases	pancreas	starch + H_2O → maltose
maltase	small intestine	maltose + H_2O → glucose

INVESTIGATION 8.4 *Introduction*

Effect of pH and Temperature on Starch Digestion

The digestion of many components of food is not accomplished in the stomach, but in the small intestine. For example, starch digestion occurs mainly in the small intestine. What happens to these components when they are in the stomach?

To perform this investigation, turn to page 275.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

DID YOU KNOW ?

Are You Lactose Intolerant?

Many people are unable to digest lactose (milk sugar) because their bodies do not produce sufficient quantities of the enzyme lactase. Normally, the disaccharide lactose is broken down into two monosaccharides, which are then absorbed into the blood. Lactose-intolerant people are unable to break down lactose in the small intestine, so when it moves to the large intestine, water is drawn in by osmosis, causing diarrhea.

Practice

1. How are the cells of the small intestine protected from stomach acid? Explain the mechanism and the chemicals involved.
2. What enzymes secreted by the pancreas promote digestion?
3. Explain the chemicals and processes involved in protein digestion and carbohydrate digestion. Why are carbohydrates not digested in the stomach?
4. List the lipid-digesting enzymes secreted from the pancreas. Do these enzymes allow for complete breakdown of lipids?
5. How is the duodenum protected against stomach acid? Why does pepsin not remain active in the duodenum?
6. In cases of extreme obesity, a section of the small intestine may be removed. What effect do you think this procedure has on the patient?
7. Describe what the inside of the small intestine looks like and how this organ increases the efficiency of its operation.

Liver and Gallbladder

The liver continually produces a fluid called bile. Bile contains **bile salts**, which aid fat digestion. When the stomach is empty, bile is stored and concentrated in the gallbladder.

When there are fats in the small intestine, the hormone **cholecystokinin** (CCK) is released. CCK is carried in the blood to the gallbladder (**Figure 5**) and triggers the gallbladder to release bile salts. Once inside the small intestine, the bile salts emulsify, or break down, large fat globules. The breakdown of fat globules into smaller droplets is physical digestion, not chemical digestion, since chemical bonds are not broken. The physical digestion prepares the fat for chemical digestion by increasing the exposed surface area on which fat-digesting enzymes, such as pancreatic lipase, can work.

bile salt a component of bile that breaks down large fat globules

cholecystokinin a hormone secreted by the small intestine that stimulates the release of bile salts

- Fats enter the duodenum and stimulate the release of the hormone CCK.
- CCK is carried by the bloodstream to the gallbladder.
- CCK stimulates the release of bile salts from the gallbladder.
- Bile emulsifies fats.

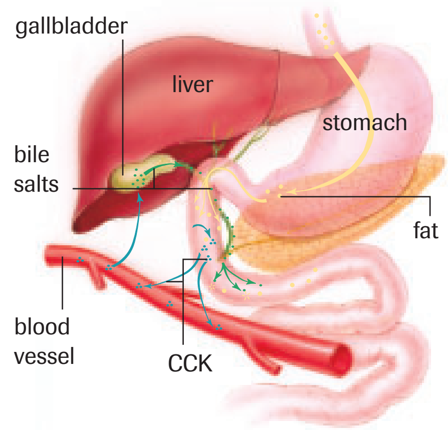


Figure 5
The function of cholecystokinin

Bile also contains pigments. The liver breaks down hemoglobin from red blood cells and stores the products in the gallbladder for removal. The characteristic brown colour of feces results from hemoglobin breakdown.

The liver also stores glycogen and vitamins A, B_{12}, and D. In addition, the liver is able to **detoxify** many substances in the body. Harmful chemicals are made soluble and can be dissolved in the blood and eliminated in the urine. One of the more common poisons is alcohol.

detoxify to remove the effects of a poison

Table 2 outlines the various functions of the liver.

Table 2 Liver Functions

Function	Examples
synthesis	• produces bile salts, which are stored in the gallbladder and which emulsify fats • manufactures blood proteins
breakdown/conversion	• removes the highly toxic nitrogen group from amino acids, forming urea (the main component of urine) • converts the toxic component of hemoglobin, allowing it to be excreted with bile salts • converts glucose into glycogen and glycogen into glucose to maintain a constant blood sugar level
storage	• stores glycogen • stores vitamins A, B_{12}, and D
detoxification	• converts harmful compounds, such as alcohol, to less harmful products

DID YOU KNOW?

Lily-Livered

The liver was once considered to be the centre of emotions. The term lily-livered, meaning cowardly, implies inadequate blood flow to the liver.

gallstone crystals of bile salts that form in the gallbladder

jaundice the yellowish discoloration of the skin and other tissues brought about by the collection of bile pigments in the blood

cirrhosis chronic inflammation of the liver tissue characterized by the growth of nonfunctioning fibrous tissue

Liver and Gallbladder Problems

The production and concentration of bile can result in certain problems. Cholesterol, an insoluble component of bile, acts as a binding agent for the salt crystals found in bile. The crystals precipitate and form larger crystals called **gallstones**. Gallstones can block the bile duct, impairing fat digestion and causing considerable pain. Any obstruction of the bile duct or accelerated destruction of red blood cells can cause **jaundice**, turning skin and other tissues yellow.

Alcohol, like many other harmful agents, can destroy liver tissue if consumed in large quantities. Damaged liver cells are replaced by fibrous connective tissue and nodules, which are not able to carry out normal liver functions. This condition, which can also result from nutritional deprivation or infection, is referred to as **cirrhosis** of the liver.

mini *Investigation* — *Emulsification of Fats*

Materials: eyedropper, test tube, vegetable oil, bile salts or liquid soap, hand lens (magnifying glass), test tube stopper

- Fill a test tube one-quarter full of water.
- Add 10 drops of vegetable oil. Record the location and appearance of the oil in the test tube.
- Shake the test tube (with stopper) and immediately examine its contents with the hand lens. Record your observations.
- Let the test tube stand for 2 min to 3 min. Observe any changes.
- Add about 5 drops of liquid soap or a pinch of bile salts to the test tube.
- Shake the test tube (with stopper). Immediately examine the contents with the hand lens and record your observations.

(a) What effect did the liquid soap or bile salts have on the oil?

colon the largest segment of the large intestine, where water reabsorption occurs

Large Intestine

Chemical digestion is complete by the time food reaches the large intestine. The **colon**, the largest part of the large intestine, must store waste long enough to reabsorb water from it. Some inorganic salts, minerals, and vitamins are also absorbed with the water.

The large intestine houses bacteria, such as *Escherichia coli (E. coli)*, which are essential to life and use waste materials to synthesize vitamins B and K. Cellulose, the long-chain carbohydrate characteristic of plant cell walls, reaches the large intestine undigested. Although cellulose cannot be broken down by humans, it serves an important function: cellulose provides bulk. As wastes build up in the large intestine, receptors in the wall of the intestine provide information to the central nervous system, which, in turn, prompts a bowel movement. The bowel movement ensures the removal of potentially toxic wastes from the body. Individuals who do not eat sufficient amounts of cellulose (roughage or fibre) have fewer bowel movements. This means that wastes and toxins remain in their bodies for longer periods of time. Scientists have determined that cancer of the colon can be related to diet. Individuals who eat mostly processed, highly refined foods are more likely to develop cancer of the colon.

EXTENSION

The Negative Impacts of Gallstones

Listen to this Audio Clip to identify the components of bile and investigate the negative effects associated with gallstones and gallbladder dysfunction.

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Practice

8. What are the components of bile? Where is bile produced and where is it stored?

9. Explain the importance of bile salts in digestion.

10. Why doesn't fat dissolve in water?

11. Why is the liver important in processing toxins in the body? What happens if the level of toxins is very high?

12. What is the function of the colon in the digestive system?

13. Why is cellulose considered to be an important part of your diet?

Control of Digestion

The control of digestion is exerted by the nervous and hormonal systems. Seeing, smelling, or tasting food will produce gastric secretions even before there is any food in the stomach. Swallowing motions also stimulate production of gastric juices, regardless of whether food is actually swallowed.

Hormones play a large role in the control mechanism. For example, secretin is released when acid from the stomach moves into the small intestine along with food. Secretin is absorbed into the blood and travels to the pancreas where it initiates the release of substances that raise the pH of the small intestine. Another hormone, called **gastrin**, is produced when the walls of the stomach are distended by the presence of food. Partially digested protein in the stomach also stimulates the release of gastrin. Gastrin travels in the blood to the parietal cells of the stomach and signals them to release HCl (**Figure 6 (a)**).

gastrin a hormone secreted by the stomach that stimulates the release of HCl

The speed at which the digestive system processes food can also be controllled. When food enters the stomach, nerves in the stomach wall cause the muscles to contract and gastric fluids to be secreted. A large meal will activate more receptors, causing more forceful stomach contractions and faster emptying. If the meal is fatty, the small intestine secretes **enterogastrone**, which slows peristaltic movements, allowing time for fat digestion and absorption (**Figure 6 (b)**).

enterogastrone a hormone secreted by the small intestine that decreases gastric secretions and motility

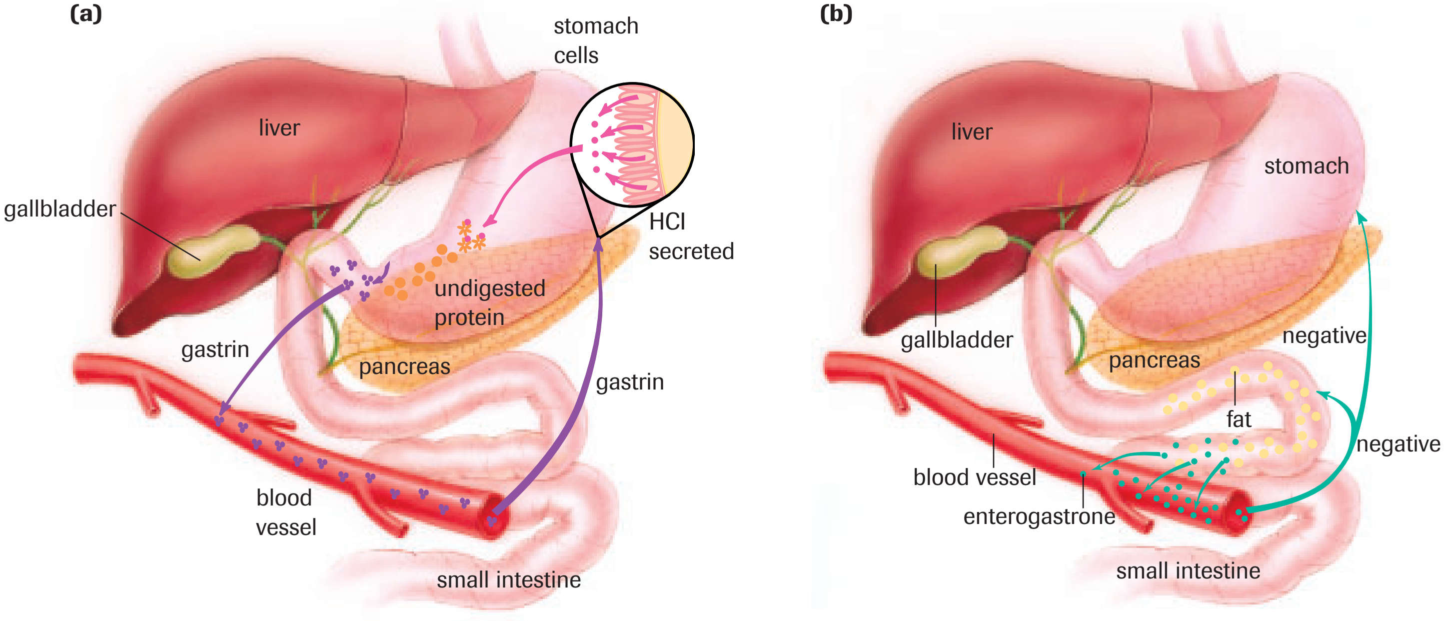

Figure 6
The function of **(a)** gastrin and **(b)** enterogastrone

SUMMARY Digestion

Table 3 Digestive Organs and Their Functions

Organ	Function
mouth	chewing of food and digestion of starch
stomach	storage of food and initial digestion of proteins
small intestine	digestion of carbohydrates, proteins, lipids; the absorption of nutrients
pancreas	production of digestive enzymes that act on food in the small intestine; storage of bicarbonate ions that neutralize stomach acid in the small intestine
large intestine	absorption of water and storage of undigested food

Table 4 Organs and Substances Involved in Digestion

Organ of secretion	Secretion	Function
salivary glands	salivary amylase	initiates the breakdown of polysaccharides to simpler carbohydrates
stomach	hydrochloric acid	converts pepsinogen to pepsin; kills microbes
	pepsinogen	when converted to pepsin, initiates the digestion of proteins
	mucus	protects the stomach from pepsin and HCl
pancreas	pancreatic amylase	continues the breakdown of carbohydrates into disaccharides
	bicarbonate ions	neutalize HCl from the stomach
	trypsinogen	when activated to trypsin, converts long-chain peptides into short-chain peptides
	lipase	breaks down fats to glycerol and fatty acids
small intestine	erepsin	completes the breakdown of proteins
	disaccharidases (e.g., maltase)	break down disaccharides (e.g., maltose) into monosaccharides
liver	bile	emulsifies fat
gallbladder	bile	stores and secretes concentrated bile from the liver
large intestine	mucus	helps movement of food waste

EXTENSION

CBC radioONE QUIRKS & QUARKS

Tummy Bugs

Dr. Lora Hooper (Washington University in St. Louis, Missouri) is part of a team that recently discovered some stomach bugs responsible for turning on our genes to aid in digestion. These bacteria also produce a chemical that strengthens the stomach lining.

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Section 8.4 Questions

1. What important physical change must fats undergo before chemical change can take place? Where and how does this physical change occur?
2. Explain the mechanism that triggers the release of bile salts.
3. Are nutrients absorbed passively or actively in the digestive tract? Where are carbohydrates, amino acids, and fats absorbed?
4. Sketch the two ways in which absorbed nutrients leave the intestine and get to body cells.
5. What are some signals that trigger the secretion of digestive fluids even in the absence of food in the stomach?
6. How do hormones help regulate digestion?
7. What are gallstones and what causes them?
8. What is jaundice? Why does this condition produce a yellowing of the skin?
9. What kind of dietary changes would a person without a gallbladder need to make? Why?
10. Research the latest techniques used in the removal of gallstones.

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INVESTIGATION 8.1

Identifying Carbohydrates

Benedict's solution identifies reducing sugars, and iodine solution identifies starches. Iodine turns blue-black in the presence of starches. The Cu^{2+} ions in the Benedict's solution are converted to Cu^{+} ions in the presence of a reducing sugar. Not all sugars are reducing sugars. All monosaccharides are reducing sugars, but some disaccharides will not react with Benedict's solution.

Table 1 summarizes the quantitative results obtained when a reducing sugar reacts with Benedict's solution.

Table 1 Reducing Sugar and Benedict's Solution Reactions

Colour of Benedict's solution	Approximate % of sugar
blue	negative
light green	0.5–1.0
green to yellow	1.0–1.5
orange	1.5–2.0
red to red brown	> 2.0

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Purpose

To identify reducing sugars qualitatively and quantitatively

Materials

- safety goggles
- lab apron
- test-tube brushes
- detergent
- 400 mL beaker
- hot plate
- thermometer or temperature probe
- 10 mL graduated cylinder
- distilled H_2O
- 5 % fructose solution
- 5 % glucose (dextrose) solution
- 5 % sucrose solution
- 5 % maltose solution
- 5 % starch solution
- 9 test tubes
- test-tube rack
- Benedict's solution
- wax pencil
- test-tube clamp
- 5 medicine droppers
- depression plates
- iodine solution
- solutions X, Y, and Z

Caution: The chemicals used are toxic and are irritants. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Procedure

Before you begin:

- Make sure that all the glassware is clean and well rinsed.
- Note the location of the eyewash station.

Part 1 : Reducing Sugars

Caution: Handle hot objects and their contents carefully to avoid burns.

1. Prepare a water bath by heating 300 mL of tap water in a 400 mL beaker until it reaches approximately 80 °C (**Figure 1**).

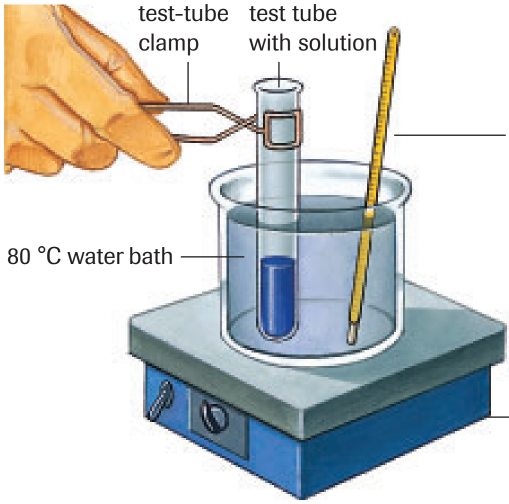

Figure 1
Heating a test tube in a hot water bath

2. Label the test tubes 1 to 6. Using a 10 mL graduated cylinder, measure 3 mL each of distilled water, fructose, glucose, maltose, sucrose, and starch solutions. Record which tube contains each solution. Pour each solution into a separate test tube. Clean and rinse the graduated cylinder after each solution. Add 1 mL of Benedict's solution to each of the test tubes.
3. Using a test-tube clamp, place each of the test tubes in the hot water bath (**Figure 1**). Observe for 6 min.

(a) Record any colour changes.

Part 2: Iodine Test

4. Using a medicine dropper, place a drop of water on a depression plate and add a drop of iodine.

(b) Record the colour of the solution.

5. Repeat the procedure, this time using drops of starch, glucose, maltose, and sucrose instead of water.

(c) Record the colour of the solutions. Which solutions indicated a positive test?

INVESTIGATION 8.1 *continued*

Part 3: Checking Unknown Solutions

6. Test the three unknown solutions for reducing sugars and starches. Design your own table, showing both qualitative and quantitative data.

(d) Record your data.

Analysis and Evaluation

(e) Why should the graduated cylinder be cleaned and rinsed after the measurement of each solution?

(f) Which test tube served as a control in the test for reducing sugars and starches?

(g) What laboratory data suggest that not all sugars are reducing sugars?

(h) A student decides to sabotage the laboratory results of his classmates and places a sugar cube into solution Z. Explain the effect of dissolving a sugar cube in the solution.

(i) A drop of iodine accidently falls on a piece of paper. Predict the colour change, if any, and provide an explanation for your prediction.

INVESTIGATION 8.2

Identifying Lipids and Proteins

In this investigation, you will use laboratory tests to identify lipids and proteins. You will then use these tests to establish which of these nutrients are present in an unknown sample. Read the investigation, then predict whether lipid, protein, or neither will be present in the unknown sample. Record your evidence, then complete the analysis and evaluation of the evidence.

Report Checklist

○ Purpose	○ Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

Problem

Does the unknown sample contain lipids or proteins?

Materials

goggles
lab apron
5–10 test tubes
test-tube rack
test-tube brush
10 mL graduated cylinder
distilled water
waterproof marker
medicine droppers
rubber stoppers
detergent solution

For lipid tests:
Sudan IV indicator
unglazed brown paper (2 letter-sized sheets)
unknown solution
vegetable oil
skim milk
whipping cream

For protein test:
Biuret reagent
gelatin
egg albumin
skim milk
unknown solution

Sudan IV indicator is flammable, and both Sudan IV and Biuret reagent are toxic and can cause an itchy rash. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Procedure

Before you begin

- make sure that all the glassware is clean and well rinsed;
- note the location of the eyewash station; and
- put on your apron and goggles.

Part 1: Sudan IV Lipid Test

Sudan IV solution is an indicator of lipids, which are soluble in certain solvents. Lipids turn from a pink to a red colour. Polar compounds will not assume the pink colour of the Sudan IV indicator.

1. Using a 10 mL graduated cylinder, measure 3 mL each of distilled water, vegetable oil, skim milk, whipping cream, and the unknown solution.
2. Pour each solution into a separate labelled test tube. Clean and rinse the graduated cylinder after each solution.
3. Add 6 drops of Sudan IV indicator to each test tube.
4. Place stoppers on the test tubes and shake them vigorously for 2 min. Record the colour of the mixtures in a chart.

Part 2: Translucence Lipid Test

Lipids can be detected using unglazed brown paper. Because lipids allow the transmission of light through the brown paper, the test is often called the translucence test.

5. Draw one circle (10 cm diameter) on a piece of unglazed brown paper.
6. Place 1 drop of water in the circle and label the circle accordingly.
7. Using more sheets, draw a total of 7 more circles (10 cm diameter).
8. Place 1 drop of vegetable oil, skim milk, whipping cream, and unknown solution, each inside its own circle, labelling the circles as you do.
9. When the water has evaporated, hold both papers to the light and observe. In a chart, record whether or not the papers appear translucent.

Part 3: Protein Test

Proteins can be detected by means of the Biuret reagent test. Biuret reagent reacts with the peptide bonds that join amino acids together, producing colour changes from blue, indicating no protein, to pink (+), violet (++), and purple (+++). The + sign indicates the relative amounts of peptide bonds.

10. Measure 2 mL of water, gelatin, albumin, skim milk, and the unknown solution into separate labelled test tubes.
11. Add 2 mL of Biuret reagent to each of the test tubes, then tap the test tubes with your fingers to mix the contents. Record any colour changes in a chart.

Analysis

(a) Explain the advantage of using two separate tests for lipids.

(b) Which test tube served as a control in the test for lipids, and proteins?

(c) Summarize your group's findings about the nutrients present in your unknown solution. Be sure to include the identifying code.

Evaluation

(d) Why should the graduated cylinder be cleaned and rinsed after measuring out each solution?

(e) List possible sources of error, and indicate how you could improve your method.

Synthesis

(f) A student heats a test tube containing a large amount of protein and Biuret reagent. She notices a colour change from violet to blue. Explain why.

(g) Predict the results of a lipid test on samples of butter and margarine.

INVESTIGATION 8.3

Factors That Affect the Catalase Enzyme Reaction

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Organisms that live in oxygen-rich environments need the catalase enzyme. The catalase enzyme breaks down hydrogen peroxide (H_2O_2), a toxin that forms readily from H_2O and O_2. The reaction below describes the effect of the catalase enzyme.

The formation of hydrogen peroxide:

$$2\ H_2O + O_2 \rightarrow 2\ H_2O_2 \text{ (hydrogen peroxide)}$$

The effect of catalase:

$$2\ H_2O_2 \xrightarrow{\text{catalase}} 2\ H_2O + O_2$$

Purpose

To identify factors that affect the rate of enzyme-catalyzed reactions

Materials

safety goggles	fine sand
lab apron	scalpel
6 test tubes	potato
waterproof marker	chicken liver (fresh)
3 % hydrogen peroxide	stirring rod
tweezers or forceps	mortar and pestle
10 mL graduated cylinder	

Caution: Hydrogen peroxide is a strong irritant. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Procedure

Part 1: Identifying the Enzyme

1. Label three clean test tubes 1, 2, and 3.
2. Using a 10 mL graduated cylinder, measure 2 mL of hydrogen peroxide and add it to test tube 1. Add a sprinkle of sand to the test tube and observe.
3. Add 2 mL of H_2O_2 to test tubes 2 and 3. Using the scalpel, remove a piece of potato approximately the size of a raisin and add it to test tube 2. Observe the reaction. Repeat the procedure once again, but this time add a piece of liver the size of a raisin to test tube 3. Observe the reaction.
4. Compare the reaction rates of the three test tubes. Use 0 to indicate little or no reaction, 1 to indicate slow, 2 to indicate moderate, 3 for fast, and 4 for very fast.

(a) Record your results.

Part 2: Factors That Affect Reaction Rates

5. Divide the hydrogen peroxide used in test tube 3 into two clean test tubes. Label one of the test tubes 4 and the other 5. Using tweezers or forceps, remove the liver from test tube 3 and divide it equally into test tubes 4 and 5. Add a second piece of liver to test tube 4 and observe. Add 1 mL of fresh hydrogen peroxide to test tube 5 and observe.

(b) Record your results.

6. Using a scalpel, cut another section of liver the size of a raisin. Add sand to a mortar and grind the liver into smaller pieces with the pestle. Remove the liver and place it in a clean test tube labelled 6. Add 2 mL of H_2O_2 and compare the reaction rate of the liver in test tube 6 with that of the uncrushed liver in test tube 3.

(c) Record your results.

Analysis and Evaluation

(d) In Part 1, which test tube served as the control?

(e) Account for the different reaction rates between the liver and potato.

(f) Explain the different reaction rates in test tubes 4 and 5.

(g) Why did the crushed liver in test tube 6 react differently from the uncrushed liver in test tube 3?

(h) Predict what would happen if the liver in test tube 3 were boiled before adding the H_2O_2. Give reasons for your prediction.

EXTENSION

Catalase and the Breakdown of Hydrogen Peroxide

Catalase plays an essential role in preventing hydrogen peroxide from reaching toxic levels. This Audio Clip explores hydrogen peroxide production in living organisms and how catalase is involved.

www.science.nelson.com GO

INVESTIGATION 8.4

Effect of pH and Temperature on Starch Digestion

Very little starch is broken down in the mouth. The low pH of the digestive fluids in the stomach halts digestion of carbohydrates such as starch until the carbohydrates leave the stomach and enter the small intestine.

Report Checklist

○ Purpose	○ Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

Purpose

To determine the pH and temperature at which amylase digests starch most quickly

Design

A cornstarch suspension will be mixed with an enzyme solution at different pH levels and at different temperatures to see which acidity level and which temperature result in the most complete breakdown of starch. The efficiency can be measured by how much sugar is produced. Benedict's reagent is used to indicate the presence of maltose, a disaccharide.

Benedict's reagent is toxic and can cause a rash. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Materials

apron
goggles
10 test tubes
1 % cornstarch suspension
Benedict's reagent
ice cubes
two 250 mL beakers
ring clamp
25 mL graduated cylinder
eyedropper
rubber stoppers for test tubes
test-tube rack
5 % amylase solutions at pH 2.0, 7.0, and 12.0
hot plate
thermometers
utility stand
tap water
labelling materials
timer or watch
glass stirring rod

Procedure

Part 1: The Effect of pH on Starch Digestion

1. Create a table in your notebook or a spreadsheet and complete it as you perform each step in the activity.
2. Put on your apron and goggles.
3. Label 4 test tubes from 1 to 4. Set up a water bath as shown in **Figure 1**.

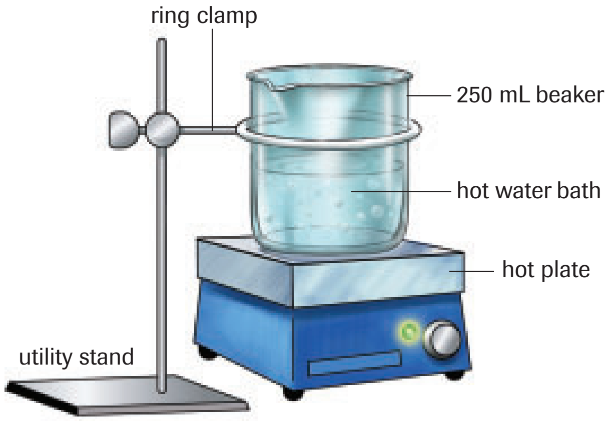

Figure 1
Water bath setup

4. Place 15 mL of the 1 % cornstarch suspension into each of the 4 test tubes.
5. Add 5 drops of the pH 2.0 amylase solution to test tube 2. Add 5 drops of the pH 7.0 amylase solution to test tube 3. Add 5 drops of the pH 12.0 amylase solution to test tube 4. Put a rubber stopper in each test tube and shake (**Figure 2**).

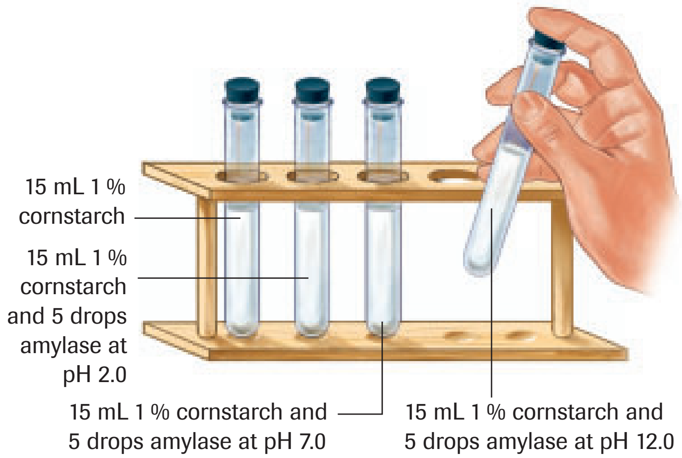

Figure 2
Test-tube setup

6. Let the test tubes sit for 20 min. Record your observations of each test tube. A colour change from blue to yellow to orange indicates maltose.

INVESTIGATION 8.4 *continued*

7. Add 5 mL of Benedict's reagent to each of the 4 test tubes and place them in the hot water bath at 100 °C. If you use the same cylinder as in Step 4, make sure to rinse and dry it first. Record your observations after 5 min. Do not let the test tubes sit in the hot water bath for more than 5 min.

Analysis

(a) In which test tube did starch digestion occur? How could you tell?

(b) What is the function of test tube 1?

(c) At what pH does amylase work best to digest starch?

Part 2: The Effect of Temperature on Starch Digestion

8. Create a table to record your data as you perform each step in the activity.
9. Label 6 test tubes from 1 to 6.
10. Place 15 mL of cornstarch suspension in each test tube.
11. Add 5 drops of amylase solution at pH 7.0 to test tubes 1, 3, and 5.
12. Place test tubes 1 and 2 in the hot water bath and heat until the cornstarch suspension reaches 50 °C. Do not heat the contents of the test tubes above 50 °C (**Figure 3**).

Figure 3
Heating the test tubes

13. Place test tubes 3 and 4 in a beaker of ice water. Let the cornstarch suspensions chill to a temperature between 0 °C and 5 °C. Stirring the water with a stirring rod may speed the cooling process.
14. Keep test tubes 5 and 6 at room temperature. Record the temperature of the cornstarch suspension.
15. Let all test tubes stand for 20 min. Maintain temperature conditions for the test tubes. Record your observations of each test tube.
16. Add 5 mL of Benedict's reagent to each test tube and place them in a hot water bath at 100 °C for 5 min. Record your observations in the table.

Analysis

(d) What would overheating have done to the contents of test tubes 1 and 2? What happens to the ability of the enzyme to convert starch to sugar at the tested temperatures?

(e) What was the function of test tubes 2, 4, and 6?

(f) At what temperature did amylase work best to convert starch to sugar?

Evaluation

(g) Identify possible sources of error, and indicate how you could improve the procedure.

Synthesis

(h) How are the conditions in the experiment similar to the conditions in the digestive system? How are they different?

Chapter 8 SUMMARY

Outcomes

Knowledge

- describe the chemical nature of carbohydrates, fats, and proteins and their enzymes, i.e., carbohydrases, proteases, and lipases (8.1)
- explain enzyme action and factors influencing that action, i.e., temperature, pH, substrate concentration, feedback inhibition, competitive inhibition (8.2)
- identify the principal structures of the digestive system, i.e., mouth, esophagus, stomach, sphincters, small and large intestines, liver, pancreas, gallbladder (8.3)
- describe the chemical and physical processing of matter through the digestive system into the bloodstream (8.4)

STS

- explain that the goal of technology is to provide solutions to practical problems by discussing and evaluating the role of food treatment to solve problems of food spoilage (8.1)
- explain that the products of technology are devices, systems, and processes that meet given needs; however, these products cannot solve all problems (8.1)

Skills

- ask questions and plan investigations (8.1, 8.2, 8.4)
- conduct investigations and gather and record data and information: by performing experiments to detect the presence of carbohydrates, proteins, and lipids (8.1) and; performing an experiment to investigate the influence of enzyme concentration, temperature, or pH on activity of enzymes (8.2, 8.4)
- analyze data and apply mathematical and conceptual models (8.2, 8.4)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

8.1

carbohydrate
polymer
monosaccharide
isomer
disaccharide
dehydration synthesis
hydrolysis
polysaccharide
starch
glycogen
cellulose
triglyceride
fat
oil
phospholipid
wax
protein
amino acid
peptide bond
polypeptide
essential amino acid
denaturation
coagulation

8.2

catalyst
enzyme
substrate
active site
cofactor
coenzyme
competitive inhibitor
feedback inhibition
precursor activity
allosteric activity

8.3

amylase
peristalsis
sphincter
mucus
pepsin
ulcer

8.4

duodenum
villi
microvilli
capillary
lacteal
secretin
enterokinase
trypsin
erepsin
lipase
bile salt
cholecystokinin
detoxify
gallstone
jaundice
cirrhosis
colon
gastrin
enterogastrone

MAKE a summary

1. In this chapter, you studied the importance of digestion in providing substances needed for energy and growth. Create a concept map that shows how the digestive system exchanges matter and energy with the environment. Check other concept maps to help you make your sketch clear.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 8
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Chapter 8 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

Use the following information to answer questions 1 and 2.

Figure 1 shows the substrates and product of an enzyme-catalyzed reaction.

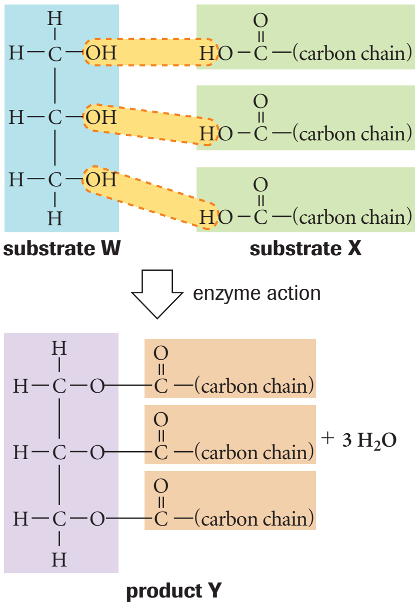

Figure 1

1. **Identify** the process and final product shown in the reaction.
   A. process is dehydration synthesis; final product (Y) is a triglyceride
   B. process is dehydration synthesis; final product (Y) is a polypeptide
   C. process is hydrolysis; final product (Y) is a triglyceride
   D. process is hydrolysis; final product (Y) is a polypeptide

2. **Identify** the initial substrates shown in the reaction.
   A. substrate W is glycerol; substrate X is a fatty acid
   B. substrate W is an amino acid; substrate X is a monosaccharide
   C. substrate W is a disaccharide; substrate X is a triglyceride
   D. substrate W is an amino acid; substrate X is glycerol

3. In chemical reactions, enzymes
   A. prevent energy loss
   B. lower the amount of energy required to initiate a chemical reaction
   C. increase the energy of the reactants
   D. decrease the energy of the final products

Use the following information to answer questions 4 and 5.

A student tested the activity of three enzymes in solutions at different pH values. The results are shown in **Figure 2**.

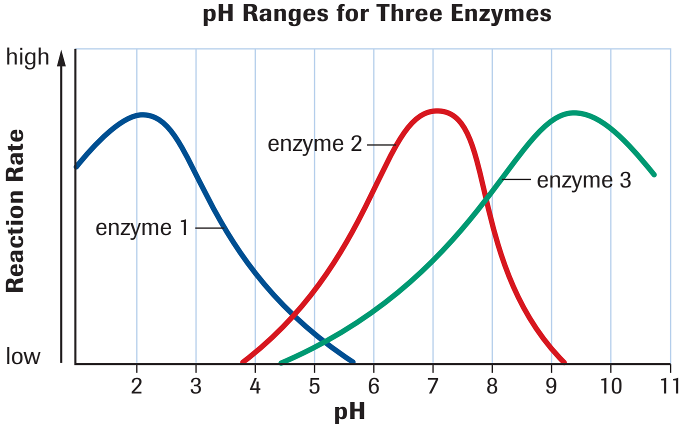

Figure 2

4. According to the data provided in the graph,
   A. enzyme 1 works best in an alkaline environment
   B. enzyme 2 works best in an acidic environment
   C. enzyme 3 works best in an alkaline environment
   D. enzymes 1 and 3 work equally well in acidic and alkaline environments

5. **Select** the optimal pH levels for enzymes 1, 2, and 3.
   A. 5; 7; 8
   B. 5.5; 4; 4.5
   C. 2; 7; 9.5
   D. 1; 9; 12

6. **Identify** why enzymes in the stomach do not digest the stomach itself.
   A. A protective mucous layer coats the stomach. Protein-digesting enzymes are stored in the inactive form.
   B. HCl is buffered to maintain a neutral pH. Fat-digesting enzymes are stored in the inactive form.
   C. A protective mucous layer coats the stomach. HCl is buffered to maintain a neutral pH.
   D. Fat-digesting enzymes are stored in the inactive form. Protein-digesting enzymes are stored in the inactive form.

Use the following information to answer questions 7 and 8.

Figure 3 shows organs of the digestive system.

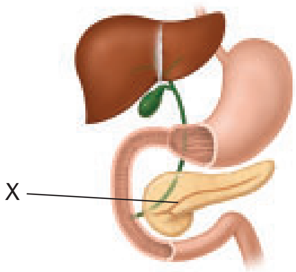

Figure 3

7. If the duct labelled X becomes blocked, the blockage would
  A. prevent pancreatic enzymes from entering the small intestine, and prevent bile salts from the liver from entering the small intestine
  B. prevent enzymes and food from the stomach from entering the small intestine, and prevent pancreatic enzymes from entering the large intestine
  C. prevent bile salts from the stomach from entering the small intestine, and prevent pancreatic enzymes from entering the small intestine
  D. prevent pancreatic enzymes from entering the large intestine, and prevent enzymes and food from the stomach from entering the small intestine

8. Identify the three food nutrients whose digestion would be impaired by the blockage of the duct.
  A. vitamins, cofactors, monosaccharides
  B. proteins, lipids, amino acids
  C. lipids, proteins, polysaccharides
  D. vitamins, amino acids, lipids

9. NR The following structures are found in the digestive system:
  1. duodenum
  2. pyloric sphincter
  3. pharynx
  4. rectum

List these structure in the order that food passes through them. (Record all four digits of your answer.)

Part 2

10. **Why** are phospholipids well suited for cell membranes?

11. DE Three different digestive fluids are placed in test tubes. The fluid placed in test tube 1 was extracted from the mouth. The fluids in test tubes 2 and 3 were extracted from what was believed to be the stomach. Five millilitres of olive oil are placed in each of the test tubes, along with a pH indicator. The initial colour of each of the solutions is red, indicating the presence of a slightly basic solution. The solution in test tube 3 turns clear after 10 min, but all of the other test tubes remain red. Write a unified response addressing the following aspects of this experiment.
- **Describe** the conclusions you would draw from the experiment.
- **Justify** each of the conclusions with the data provided. (*Hint:* Consider which substance is digested. What are the structural components?)

Use the following information to answer questions 12 to 14.

Data were collected from two different chemical reactions and are displayed in **Figure 4**.

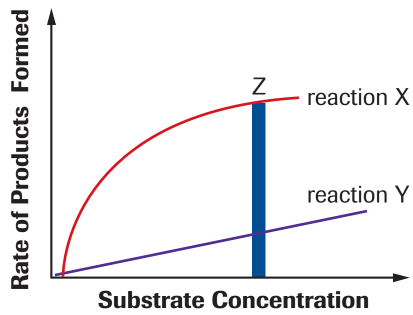

Figure 4

12. DE Identify the reaction that would most likely represent an enzyme-catalyzed reaction. **Explain** why.

13. DE **Why** does reaction X begin to level off at point Z?

14. DE **Predict** how the reaction curve would change if additional enzymes were added to both reaction X and reaction Y. **Explain** your prediction.

15. If a molecule similar to substrate “R” attaches itself to enzyme “r,” **how** might the reaction in **Figure 5** be affected?

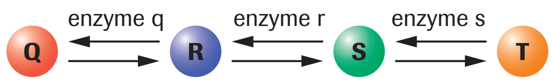

Figure 5

16. **Why** are pepsin and trypsin stored in inactive forms? Why can erepsins be stored in active forms?

17. Under certain abnormal conditions, the stomach does not secrete hydrochloric acid. **Identify** two functions that hydrochloric acid has in the digestive process and **describe** how the failure to secrete hydrochloric acid will affect these processes.

18. **Why** do individuals with gallstones experience problems digesting certain foods?

19. **Why** might individuals with an obstructed bile duct develop jaundice?